Advanced Engineering Design Modelling

By Christopher John

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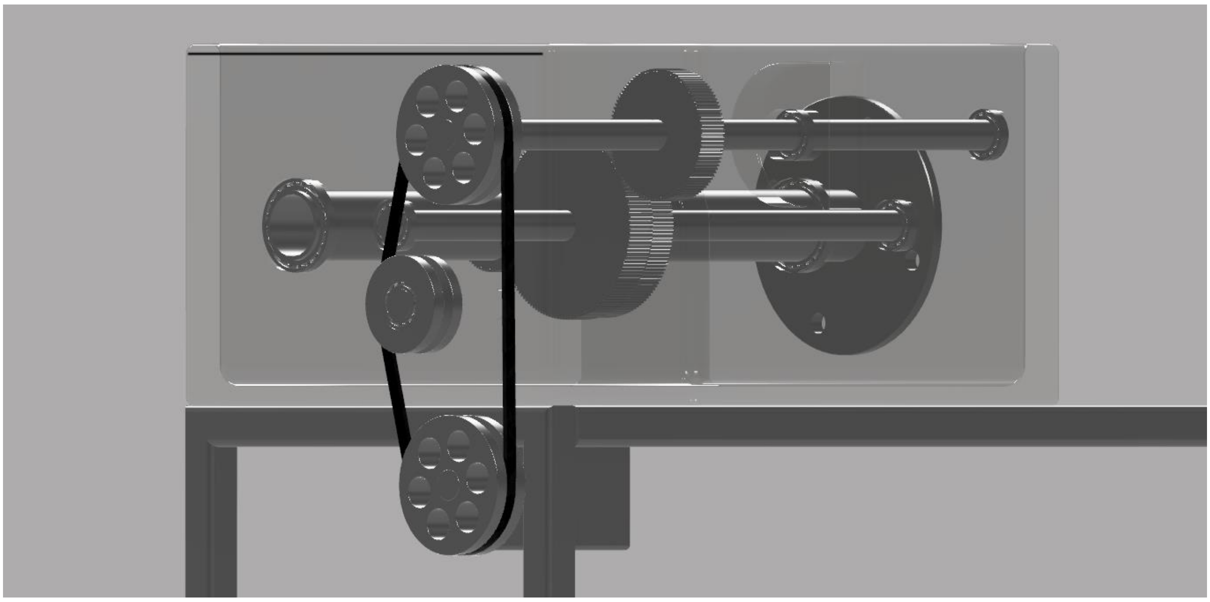
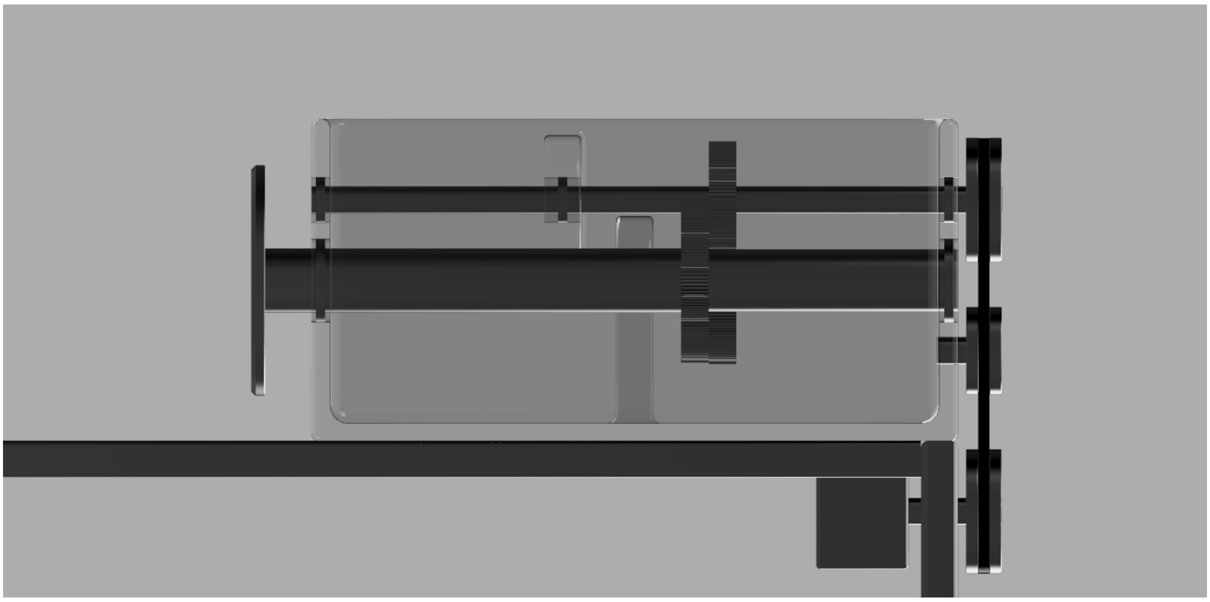




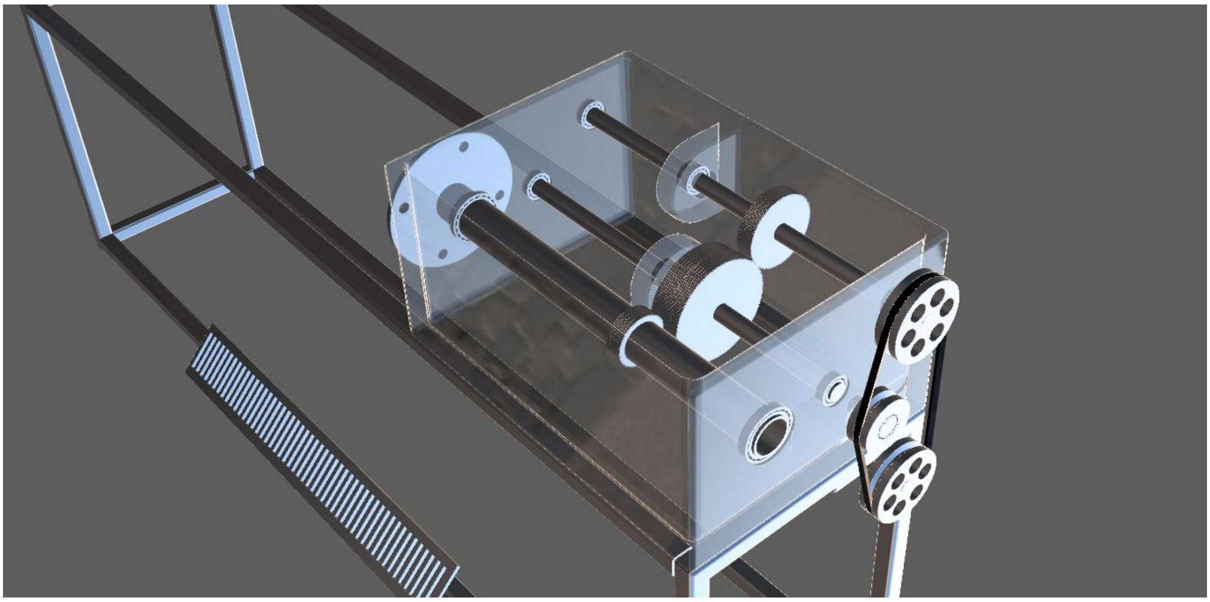
Summary

The project given to students at Loughborough College is based on the design of a pulley system for a 2.2 Kw Lathe Machine.

The design is to utilise two types of belt system, incorporate a hypothetical braking mechanism that does not need to be shown via SolidWorks, but does need to be designed and mentioned.

This report will show two systems identical; the difference is the Belts, I will compare designs and choose the most suitable, at this point I will add the brake.

To determine the outcome, I will be using research and development, tables and matrix charts, hand calculations and my own initiative to solve the problem.



Acknowledgements

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Introduction

We have been given a simple Lathe design in SolidWorks CAD, and a brief to follow it up.

The idea of the brief is to design a Flat belt, a V belt and a Hydraulic brake mechanism for the lathe given, at this point I do not know anything, I have no experience working with a lathe. To gain knowledge I am going to do some research into how this could be achieved. Once I select a Belt Type, I will then add a brake system.

Note: calculations regarding the brake will incorporate the belt selected.

A thorough investigation into the problem is required, methods such as decision matrix, hand calculations, CAD and research will give an insight into what is required and will lead to a critically evaluated conclusion.

(Durabelt.com, 2017)

Material Selection

V Belt Material

Rubber

Rubber is amorphous, the elastomer happens naturally and comes from the latex of certain trees and plants. After latex is processed, it becomes an elastomer with good mechanical properties. It has good tensile strength and elongation; it is tear resistance and resilient. It has a Useful temperature range (-55° C to + 82° C).

Properties

Table 1 Rubber Properties

Spec heat (°)	Spec gravity (°)	Density kg/m^3	Tensile strength (Mpa)	Tensile Modula's (MPa)	Temperature (°)	PIOSSON RATIOS	Friction Coefficient	Hardness durometer
45-90	0.934 @ (20°)	0.91-104	10-25	0.001	-55 ° - +82°	0 - 0.5	0.25-0.85	70 durometer

Structure

Elastomers are obtained naturally. It is made up of solid particles suspended in a milky white liquid, this is what we call latex. see structure below.

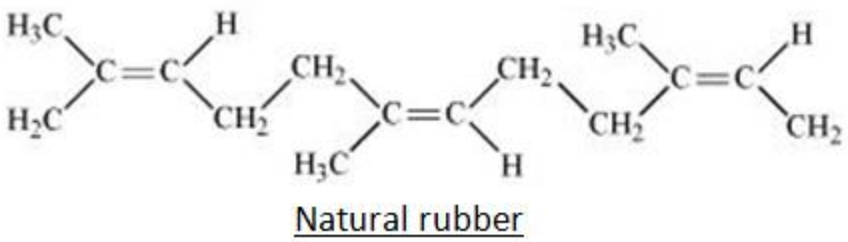


Figure 1 Structure of Rubber

(Encyclopaedia Britannica, 2017)

Polyethylene Terephthalate (PET)

Background PET

Polyethylene terephthalate (PET), is the most common thermoplastic polyester and is normally called polyester, see chart below for properties.

Strength and Hardness of PET

Table 2 PET Properties

Coefficient of friction	0.2-0.4
Hardness – Rockwell	M94-101
Izod impact strength ($J.m^{-1}$)	13-35
Poisson’s ratio	0.37-0.44(oriented)
Tensile modulus (GPa)	2-4
Tensile strength (MPa)	80, for biax film 190-260

Physical Properties

Table 3 PET Physical Properties

Density ($g.cm^{-3}$)	1.3-1.4
Flammability	Self-Extinguishing
Limiting oxygen index (%)	21
Refractive index	1.58-1.64
Resistance to Ultra-violet	Good
Water absorption - equilibrium (%)	<0.7
Water absorption - over 24 hours (%)	0.1
Coefficient of thermal expansion ($x10^{-6}$ K^{-1})	20-80

Heat-deflection temperature - 0.45MPa (°C)	115
Heat-deflection temperature - 1.8MPa (°C)	80
Lower working temperature (°C)	-40 to -60
Specific heat (J.K-1.kg^{-1})	1200 - 1350
Thermal conductivity (W.m^{-1}. K^{-1})	0.15-0.4 @ 23
Upper working temperature (°C)	115-170

(Encyclopaedia Britannica, 2017)

Structure

PET has a chemical composition of C, H, and O, and it can be expected to be highly infrared active.

Chemical structure

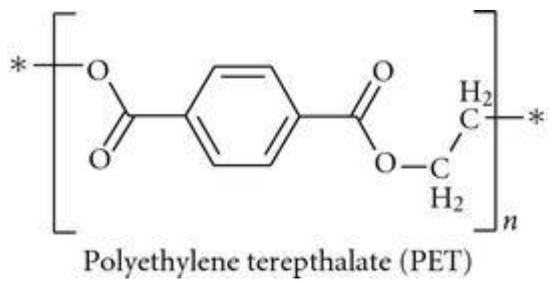


Figure 2 Structure of Polyethylene terephthalate

(Prasad, De and De, 2017)

Combination of Rubber and PET makes excellent material for Flat and V belt.

Flat belt materials

Nylon and Rubber Mix

Nylon properties

Table 4 Nylon Properties

Density	1.15 g/cm^3
Electrical conductivity (σ)	10^{-12} S/m
Thermal conductivity	0.25 W/(m·K)
Melting point	463–624 K 190–350 °C 374–663 °F

Nylon is a polyamide and used for synthetic fibres in clothing. Nylon can also be used to make other materials, such as string or ropes, it can be mixed with other materials such as rubber, for example a V or Flat Belt for a lathe.

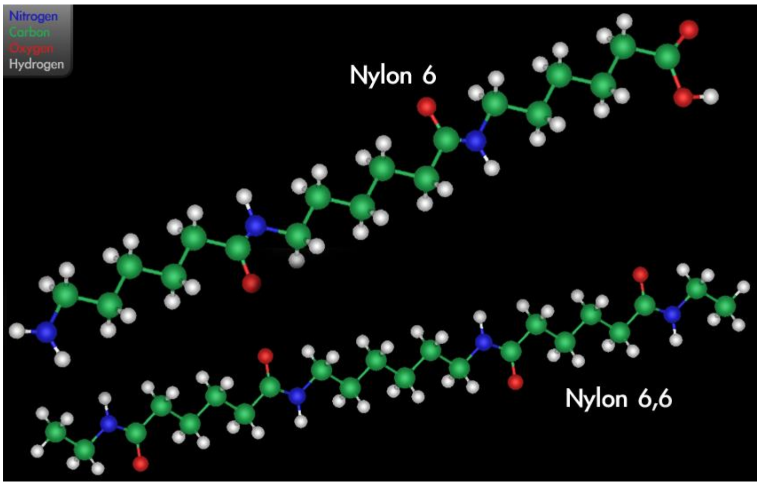


Figure 3 Structure of Nylon

(Jcfa.gr.jp, 2017)

Nylon in Flat Belts

Flat belts are endlessly woven to retain strength when made with nylon reinforced rubber. This gives belts a good mechanical performance, with a high friction coefficient. Also gives a vibration free drive at high speeds with minimal maintenance.

Mixed with Rubber

Nylon is vulcanised with rubber, same as PET, which adds a lot of strength and flexibility. Nylon corded belts are made up of multiple cords, in-cased in rubber and then covered with a fabric or a runner. These belts are classed as heavy duty and used at high speeds. (Bearingsrus.co.uk, 2017)

Material of Pulley and Idler

Ductile iron 65-45-12

This iron contains nodular graphite in a matrix of ferrite with small amounts of pearlite, very good machinability, and good surface finish, has good strengths in fatigue, conductivity and magnetic ability. This iron has same tensile strength as AISI 120 Steel in the cold rolled condition, but half the safety factor according to SolidWorks FEA Analysis.

Iron

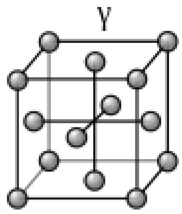


Figure 4 Structure of Ductile Iron

Face Centre Cubic (FCC), lattice structure

FCC means that the atoms can slide more easily over each other making the properties of the materials ductile. Ideally for pulley speeds less than 35 m/s.

The microstructure consists of type 1 and 2 nodular graphite, the matrix is ferrite with 5-25% pearlite, the rim always has a higher nodular count and is mostly ferrite, the chill carbides will be less than 5% in any field.

Ductile Iron Properties

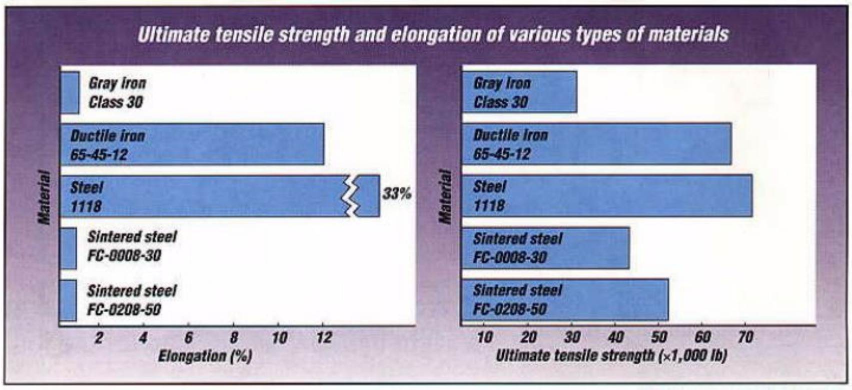


Figure 5 Ductile iron 65-45-12 Tensile Strength

(Ww2.gates.com, 2017)

Composite

Table 5 Ductile Iron Properties

	C	Mn	Si	Cr	Ni	Cu	Mg
Min%	3.4		2.35				0.025
Max%	3.8	0.4	2.75	0.08	0.5	0.4	0.055

Physical and Mechanical Properties

Table 6 Physical and Mechanical Properties

UTS	65000
TS	45000
%Elongation	12%
Hardness	
Density lb/in^3 (g/cm^3)	0.256(7.1)
Thermal Conductivity Btu/hr·ft·F (W/m·K)	250(36) for Ferritic grades, will change with an increase in pearlite, approx. 20% less
Specific Heat at 70F Btu/lb·F (J/Kg·k)	0.110(461)
Coefficient of Thermal Expansion/F(Ɛ/C)X10^6 average between 68-212F	6.4 (11.5)
Melting Temperature (F)	2100 F
Compressive Strength Ksi (MPa)	429 (2960)

(Ww2.gates.com, 2017)

Drive Shaft

Cold Rolled AISI 1020 Steel **(Optimised, See FEA)**

Mechanical Properties AISI 1020 steel Cold Rolled

Optimizing suggests, cold rolled steel has similar strengths to Ductile Iron, but is easier to bend and break, according to FEA safety factor results. Cold Rolled is a precise way of shaping metal objects without degrading or deforming. Below is a chart that compares Hot Rolled to Cold Rolled, to show benefits.

(Capitalsteel.net, 2017)

Table 7 Cold Rolled AISI 1020 Steel Properties

	Hot Rolled	Cold Rolled
Tensile Strength	67,000 psi	85,000 psi
Yield Strength	45,000 psi	70,000 psi
Reduction of Area	58	55
Elongation in 2"	36	28
Brinell Hardness	137	167

Thermal Expansion

- Thermal Expansion
- Tolerance

Thermal Expansion Method for connection.

Thermal expansion is the tendency of matter to change in shape, area, and volume in response to a change in temperature.

Shrink Fitting

When Liquid nitrogen is at - 196°C, it is great for shrinking shafts, drums or spigots, this method allows for perfect fits for equipment and machines. Liquid Nitrogen expands when rising to room temperature and forms very strong joints without disturbing the structure of material. Liquid nitrogen shrink fitting is one of the safest methods of assembling components. The components are put under no stress. Shrink fitting is at times the only method available, for example when a weld or solder cannot be achieved to connect materials.

Bearing to drive shaft connection.

Tolerance interference fit.

+0.100 - 0.100

Diameter of shaft 30mm @ 20°C

@ - 196°C 29.900mm after 5 minutes.

Diameter of bearing 29.950mm @ 20°C

(Google Books, 2017)

Hand Calculations

Lathe Gear Box

A-B

$$\frac{D_A}{D_B}\ X\ rpm$$

$$= \frac{125}{178.75} X\ 1430 = 1000\ rpm$$

= 1000 rpm

B-C

(compound gear same speed as B)

= 1000 rpm

C-D

$$\frac{D_C}{D_D}\ X\ rpm$$

$$= \frac{175}{87.5} X\ 1000 = 2000\ rpm$$

= 2000 rpm

Input 1430 rpm

Output 2000 rpm

Symbols list

Table 8 Symbols List

Service Factor = 1.4 (sf)
D = Diameter
r = Radius (57.5mm)
W = Angular velocity
V = m/s (meters per second)
Lp = Pitch Length (338mm)
e = 2.718
µ = Friction (flat 0.25) (v .038)
T = Torque

N = Newton
Rpm = Radians θ
Dp = Driver pulley (115mm)
Dp = Driven pulley (115mm)
RPM = 1430 (convert to rads)
m = Mass
G = 9.81
h = Height
KE = Kinetic Energy
PE = Potential Energy
j = Joules

V Belt Calculations

Angular Velocity Ratio

$$\mathrm{VR} = \frac{\mathrm{w}_1}{\mathrm{w}_2} = \frac{\mathrm{D}_2}{\mathrm{D}_1}$$

$\mathrm{VR} = \frac{1430}{1430} = \frac{0.115}{0.115}$ = 1:1 Ratio

Design Power

Motor x service factor

Motor = 2.2 kW

Service factor = 1.4 (see fig 13)

2.2 x 1.4 = 3.1

Design power = 3.1kW = class A, (V Belt)

Lap Angle

$$\theta_1 = 180 - 2sin^{-1}\left[\frac{D_2 - D_1}{2C}\right]$$

$$\theta_1 = 180 - 2 \times \left(sin^{-1}\left[\frac{115 - 115}{2 \times 338}\right]\right)$$

$$\theta_1 = 180°$$

Arc of contact, factor = 1

(Megadynegroup.com, 2017)

Belt Speed

$v = \frac{\pi n d}{60}$

$v = \frac{\pi x 1430 x 0.115}{60}$ = 8.6

m/s = 8.6

Friction and Tension Factor

$\frac{T_1}{T_2}$ = $\frac{0.25}{Sin\ 40°}$ = 0.38 μ

$\frac{T_1}{T_2} = e^{\mu\theta}$

$\frac{T_1}{T_2} = e^{0.38\ X\ 3.14}$ = 3.3μ

Belt Tension

3.3 x $T_1 - T_1$ = 7.59N

3.3/$T_1 - T_1$ = 2.3N

T1 = 7.59N

T2 = 2.3N

7.59/2.3 = 3.3N

$\textbf{Torque on driving pulley} = \mathrm{T_1 r_1 - T_2 r_2 = (T_1 - T_2) r_1}$

= 302.45N

$\textbf{Torque on driven pulley} = \mathrm{T_1 r_2 - T_2 r_2 = (T_1 - T_2) r_2}$

= 302.45N

Torque = 604.9N

Power Transmitted

v = 8.6 m/s

T_1 = 7.59N T_2 = 2.3N

$\text{Transmitted Power(P)} = (\mathrm{T_1 - T_2})\mathrm{v}$

(7.59 - 2.3) x 8.6 = 45.5 Kw

Or

$\text{Transmitted Power (P)} = 7.59 \times 10^3 (1 - \mathrm{e}^{-0.38\mathrm{x}3.14})\mathrm{x}8.6$

= 45.4 kW

Note: The angle of lap (θ) is in radians

Belt Calculation

C = centre distance between shafts = 338mm, worked out using SolidWorks Measurement.

$$L = 2c + 1.57x(Dp + dp) + \frac{(Dp - dp)^2}{4c}$$

$$Lp = 338x2 + 1.57x(115 + 115) + \frac{(115 - 115)^2}{4x338} = 1037.1mm$$

Effective Belt Length

$Lp - 2\ x\ h\ x\ \pi$

$1037.1 - 2\ x\ 9\ x\ \pi$ = 980mm (Length Pitch)

Flat Belt Calculations

Angular Velocity Ratio

$$\mathrm{VR} = \frac{\mathrm{w}_1}{\mathrm{w}_2} = \frac{\mathrm{D}_2}{\mathrm{D}_1}$$

$\mathrm{VR} = \frac{1430}{1430} = \frac{0.115}{0.115}$ = 1:1 Ratio

Lap Angle

$$\theta_1 = 180 - 2sin^{-1}\left[\frac{D_2 - D_1}{2C}\right]$$

$$\theta_1 = 180 - 2 \times \left(sin^{-1}\left[\frac{115 - 115}{2 \times 338}\right]\right)$$

$$\theta_1 = 180°$$

Arc of contact, factor = 1

(Megadynegroup.com, 2017)

Belt Speed

$$v = \frac{\pi n d}{60}$$

$$v = \frac{\pi x 1430 x 0.115}{60}$$ = 8.6

m/s = 8.6

Friction Factor

$\mu = 0.25$

$\frac{T_1}{T_2} = e^{\mu\theta}$

$\frac{T_1}{T_2} = e^{0.25X3.14}$ = 2.2μ

Belt Tension

2.2 x T_1 – T_1 = 2.64 tight side

2.2/T_1 – T_1 = 1.2 slack side

T_1 = 2.64 N

T_2 = 1.2 N

2.64/1.2 = 2.2 N

$r_1 = 57.5mm$ (Radius of Driver and Driven Pulleys)

Torque on driving pulley $= T_1 r_1 - T_2 r_2 = (T_1 - T_2) r_1$

= 82.8N

Torque on driven pulley $= T_1 r_2 - T_2 r_2 = (T_1 - T_2) r_2$

= 82.8N

Torque = 165.6N

Power Transmitted

v = 8.6 m/s

T_1 = 2.64N T_2 = 1.2N

$(P) = (T_1 - T_2) v$

(2.64 – 1.2) x 8.6 = 12.3 kW

Or

$\text{Transmitted Power (P)} = 2.64(1 - \mathrm{e}^{-0.25\mathrm{x}3.14})\mathrm{x}8.6$

= 12.3 kW

Note: The angle of lap (θ) is in radians

Belt Calculation

C = centre distance between shafts = 338mm, worked out using SolidWorks Measurement.

$$L = 2c + 1.57x(Dp + dp) + \frac{(Dp - dp)^2}{4c}$$

$$Lp = 338x2 + 1.57x(115 + 115) + \frac{(115 - 115)^2}{4x338} = 1037.1mm$$

Effective Belt Length

$Lp - 2\ x\ h\ x\ \pi$

$1037.1 - 2\ x\ 1\ x\ \pi = 1030.8mm$ (Pitch Length)

Thickness calculation

1 plie = 10m/s

1 x Plie = 1mm

1 x 1 = 1mm thick

W = 20mm (same as V belt surface contact area for comparison and selection)

Drive Shaft Torsion

Tensile/safety factor

$= \frac{551}{5}$

$= 110.2\ N/mm^2$

Angular velocity

$$\omega = \frac{2\pi \times 1430}{60}$$

$$= 149.75\, rad/sec$$

$$P = T\omega$$

$$T = \frac{P}{w}$$

$$T = \frac{2200}{149.75}$$

$$T = 14.69\ Nm$$

$$T = 1469\ Nmm$$

$$J = \frac{\pi D^4}{32}$$

$$\frac{T}{J} = \frac{\tau}{r}$$

$$\frac{T}{\pi D^4/32} = \frac{\tau}{r}$$

$$\frac{1469}{\pi D^4/32} = \frac{110.2}{D/2}$$

$$1469 \times \frac{32}{\pi D^4} = 110.2 \times \frac{2}{D}$$

$$\frac{1847}{\pi D^4} = \frac{220.4}{D}$$

$$\frac{1847}{220.4} = \frac{\pi D^4}{D}$$

$$8380 = \pi D^3$$

$$\frac{8380}{\pi} = D^3$$

$$2667.4 = D^3$$

$$\sqrt[3]{2667.43} = D$$

$$13.8mm = D$$

$$Chosen\ shaft\ diameter = 30mm$$

Brake calculations

Net Weight

35kg

Excludes frame and housing of V belt lathe, includes everything else, weighed using SolidWorks

Force on Lathe

Force = Mass x acceleration

35kg x 8.6 m/s = 301N

Force = 301N

Work done to Power the Motor

$w = \frac{2.2x10^3x149.75}{60}$ = 14.69 N-m / s

Force + Motor Force

301 + 14.69 = 315.69N of force on Newtons acting on lathe

Brake Force Required

Must be Greater than 315.69N

Stopping Distance

Lathe should stop within 10 seconds (EU regulation) without out a brake.

Belt speed 8.6m/s

V belt friction factor = 0.38μ

$$\frac{v^2}{2x\mu xg}$$

$\frac{8.6^2}{2x0.38x9.81}$ = 9.9 second

Within guidelines, but time consuming and costly if you're stopping the lathe frequently so a brake is required.

Braking Force

KE = $\frac{1}{2}$ mv^2

= $\frac{1}{2}$ x 35 x 8.6^2

= 1294.3j $^{\text{(starting point)}}$

PE = mgh

h = belt length run down time over 9.9 seconds naturally = 86 metres

35 x 9.81 x 86 = 29528.1j

KE + PE

1294.3+ 29528.1 = 30822.4j Joules

Work Done

F x D = $\frac{work}{d}$ = $\frac{30822.4}{86}$ = 358.4N

358.4N is the force required to deliver effective braking to the 315.69N rotating force. Kinetic Energy must be considered.

Specification and Parameters

Parametric design

The parameters of the lathe dictate the design specification constraints, all parts fit the parameters of the Lathes original design. The housing face for pulley parameters are below.

- Height = 350mm
- Length = 700mm
- Width = 500mm

All work fits within this parameter.

V Belt Pulley Specification

Table 9 V Belt Pulley Specification

Application	Cutting Material	Motor Class, and Service Factor	Motor Input Kw Driver (RPM)	Driven Shaft Output (RPM)	Spindle Output (RPM)	Pulley Diameter	Tensioner Idler Diameter	Belt Speed	Belt Weight	Design Power
Lathe	Steel	A / 1.4	2.2kw/1430	1430	2000	115mm	85mm	8.6 M/S	130g	3.1Kw

Standards V Belt

API 1B, RMA IP 20, DIN 2215, ISO 4184 and BS3790

V Belt Driver and Driven Pulley Dimensions

Table 10 V Belt Driver and Driven Pulley Dimensions

125mm outside diameter
115mm belt to pulley diameter
Width 37.5mm
30mm diameter hole centred
30mm diameter hole x 6, centred from pitch edge to centre hole edge.
1mm fillet outside edges
Centre to centre = 338mm

V Belt Tension Idler Dimension

Table 11 V Belt Tension Idler Dimension

85mm pitch diameter
95mm Outside diameter
1mm clearance belt to pulley.
Width 37.5mm

1mm Fillet
50mm centre hole for bearing
Central to 115mm pulleys, vertically and horizontally.

Idler Shaft Tensioned

Table 12 Idler Shaft Tensioned

30mm Height
70mm length

V Belt Dimensions

Table 13 V Belt Dimensions

Length = 1040mm
Width 12.5mm (top)
Height 9mm
Clearance 1mm
40° angle
1mm gap
Surface contact = 20mm
Friction Coefficient = 0.38 μ (belt to pulley surface)

This allows for the v belt dimensions concluded that a class A type v belt should be 12.5mm in width, 9mm in height, with a 40-degree angle, giving the v design.

Based on cost, the diameter of the pulleys will be 125mm overall, which allows for the correct V belt to be fitted at 115mm, and the correct tolerance, pulley to belt surface.

Motor and Shaft

Table 14 Motor and Shaft

2.2kw 3 (hp)
Width 100mm
Height 150mm
100mm extrude
50mm bearing housing
30mm diameter shaft central
Length 100mm

V Belt Material

Table 15 V Belt Lathe Material

Motor Material	**Idler Shaft**	**V Belt Material**	**Pulley and Idler Material**
Steel	Cold Rolled AISI Steel	(PET) Rubber Friction = 0.38µ	Ductile Iron 65-45-12

Flat Belt Pulley Specification

Table 16 Flat Belt Pulley Specification

Application	Cutting Material	Motor Class, and service factor	Motor Input kw driver (RPM)	Driven Shaft Output (RPM)	Spindle Output (RPM)	Pulley Diameter Pitch	Tensioner Idler Diameter Pitch	Belt Speed	Belt Weight	Design Power
Lathe	Steel	A / 1.4	2.2kw/1430	1430	2000	115mm	85mm	8.6 m/s	25g	3.1Kw

Standards

JIS B 1852

ISO 22

Flat Belt Driver and Driven Pulley Dimensions

Table 17 Flat Belt Driver and Driven Pulley Dimensions

125mm outside diameter
115mm belt to pulley diameter
9mm Lip
Width 50mm
30mm diameter hole centred
30mm diameter hole x 6, centred from pitch edge to centre hole.
1mm fillet outside edges

Flat Belt Idler Dimension

Table 18 Flat Belt Idler Dimension

90mm diameter pitch
95mm Outside diameter (half size of pulley Lip)
Width 50mm
50mm centre hole for bearing
Centre to centre 338mm

Idler Shaft Tensioned

Table 19 Idler Shaft Tensioned

30mm Height
70mm length

Flat Belt Dimensions

Table 20 Flat Belt Dimensions

Length 1040mm
Width 20mm
Height 1 mm
Friction Coefficient = 0.25 μ (belt to pulley surface)

Tracker

Table 21 Tracker

Height 0.4mm central
Length 6.8mm

Motor and Shaft

Table 22 Motor and Shaft

Width 100mm
Height 150mm
100mm extrude
30mm diameter shaft central
50mm bearing allowance central to shaft
Length 100mm

Flat Belt Lathe Material

Table 23 Flat Belt Lathe Material

Motor Material	Idler Shaft	Flat Belt Material	Pulley and Idler Material
Steel	Cold Rolled AISI Steel	Nylon and Rubber Friction = 0.25µ	Ductile Iron 65-45-12

Bearings

The ball bearing is a type of rolling-element bearing, it uses balls to sustain separation between bearing races. A ball bearing is used to reduce rotational friction of components and supports axial and radial loads. A bearings load transmits from the outer race, to the ball, and then from the ball to the inner race. A ball is a sphere, it only contacts the inner and outer race at tiny points, which helps it spin very smoothly, but loads applied can cause the bearings to deform if material selection is wrong. We have been given Ball thrust Bearings buy the College to use within the design. Below is a picture naming the parts.

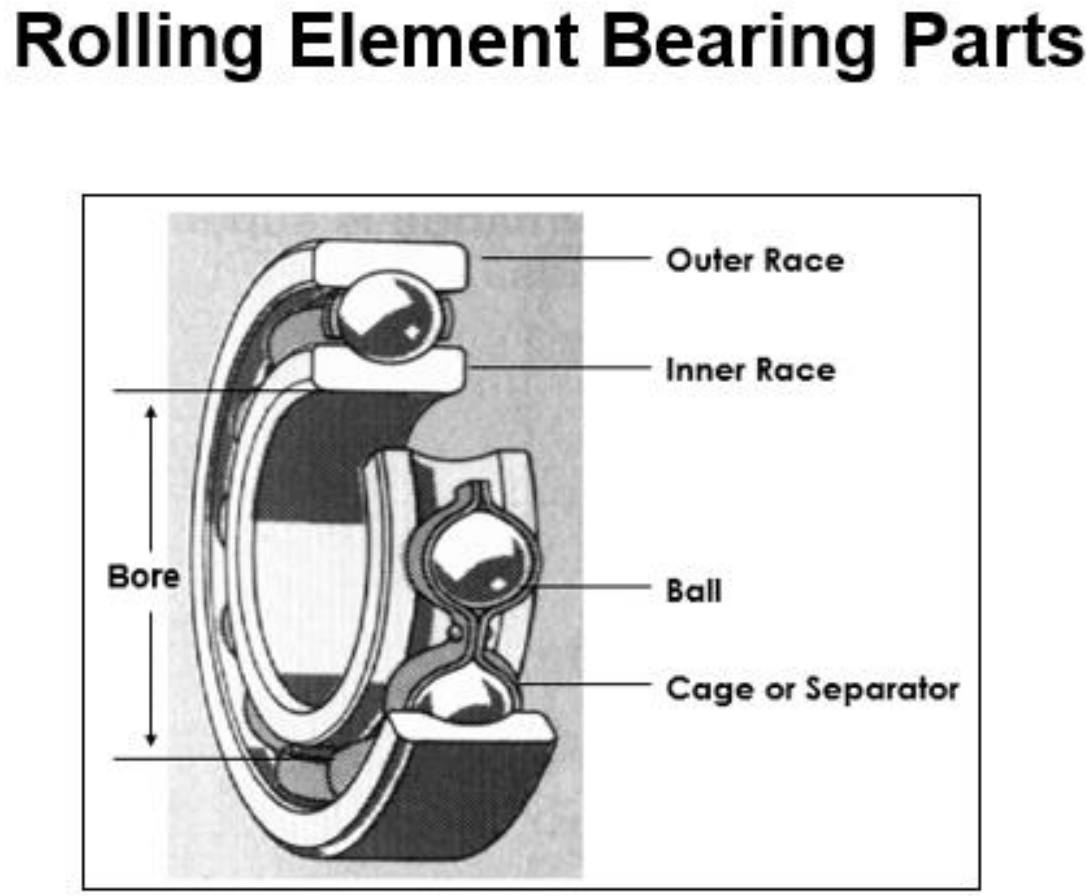


Figure 6 Rolling Bearing Components

Lathe Report

Introduction

This report shows the method I chose to select components and outcomes. Which concluded in the choice of belt I would add a brake mechanism to.

My Input

I will be using just one belt instead of two, design power states that a single belt is ample, the argument is if you buy two belts at the same time, with same lifespan, you can guess you will change them together, or one will last a little bit longer, when one breaks it may clog the drive of the other belt. It is expensive and achieves little, efficiency and sustainability are key factors, my design is not so detrimental that a broken belt is the end of the world, and as the belt is clearly visible on the side of the Lathe, faults are quickly identified and rectified.

Brainstorming Ideas of Design

Four, rough sketch, design idea drawings, have been put forward.

Drawing 1

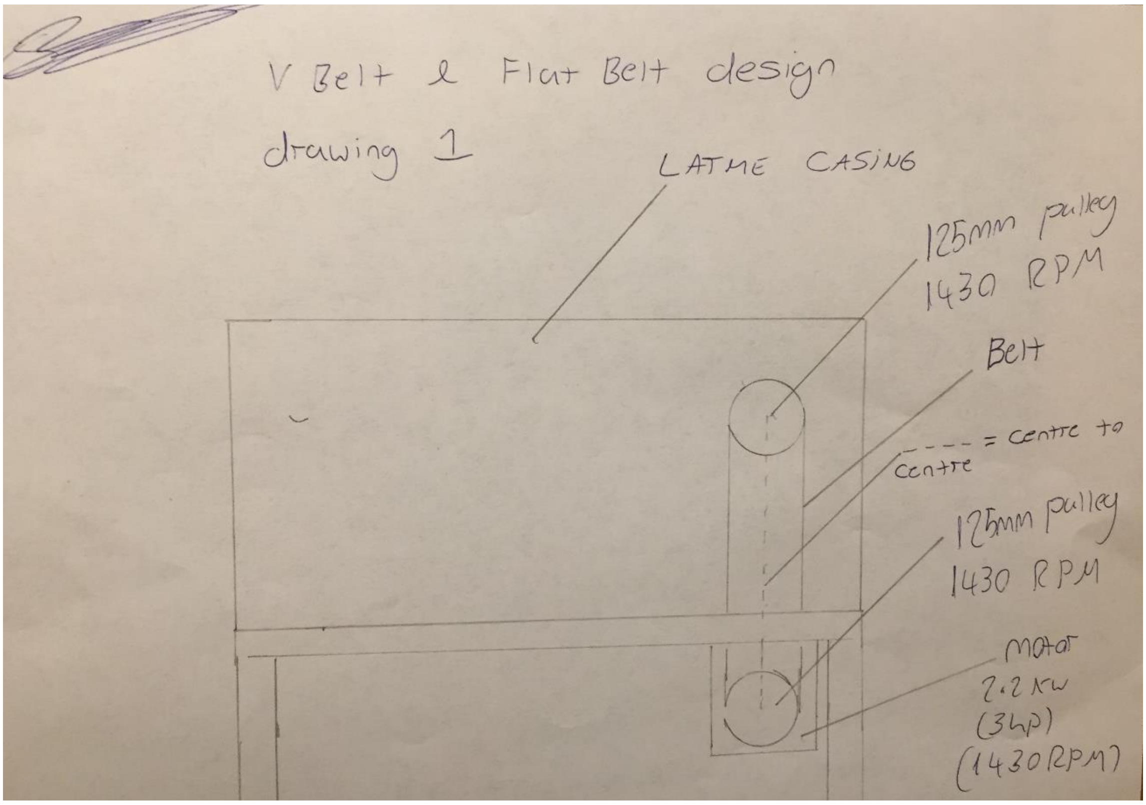


Figure 7 Drawing 1

Drawing 2

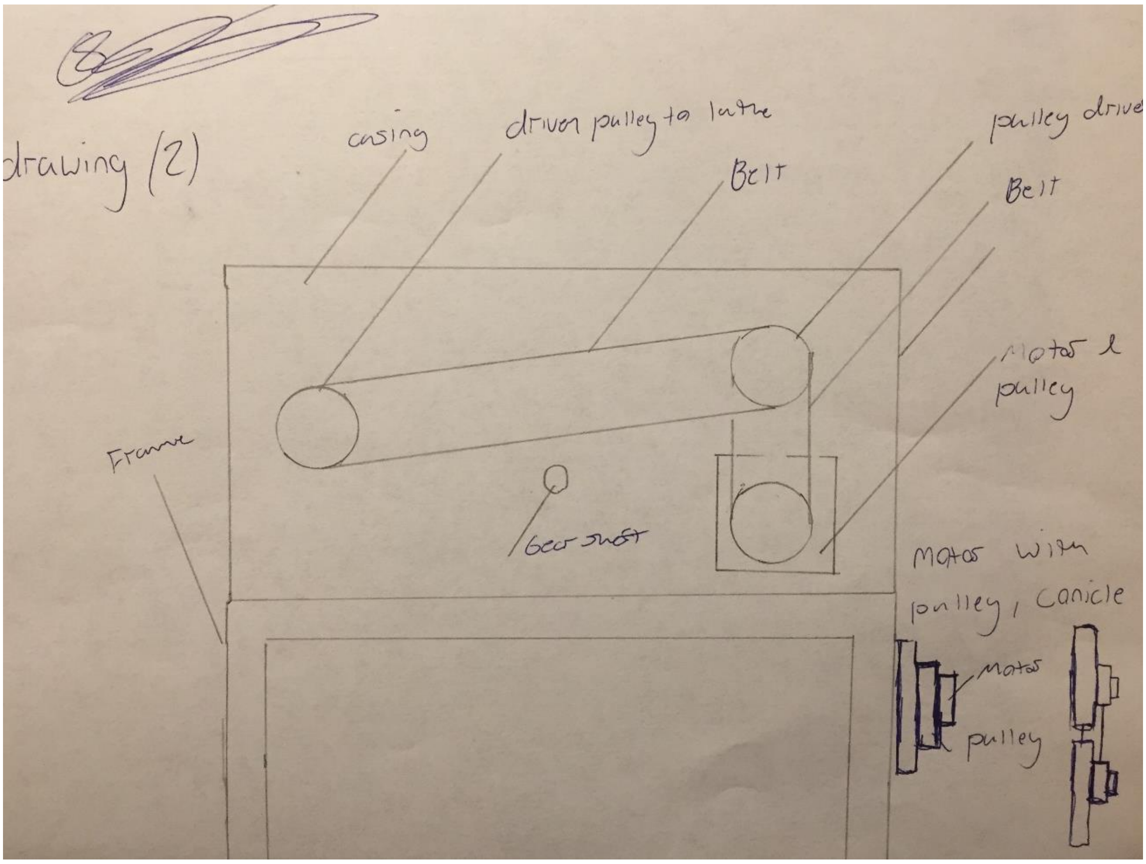


Figure 8 Drawing 2

Drawing 3

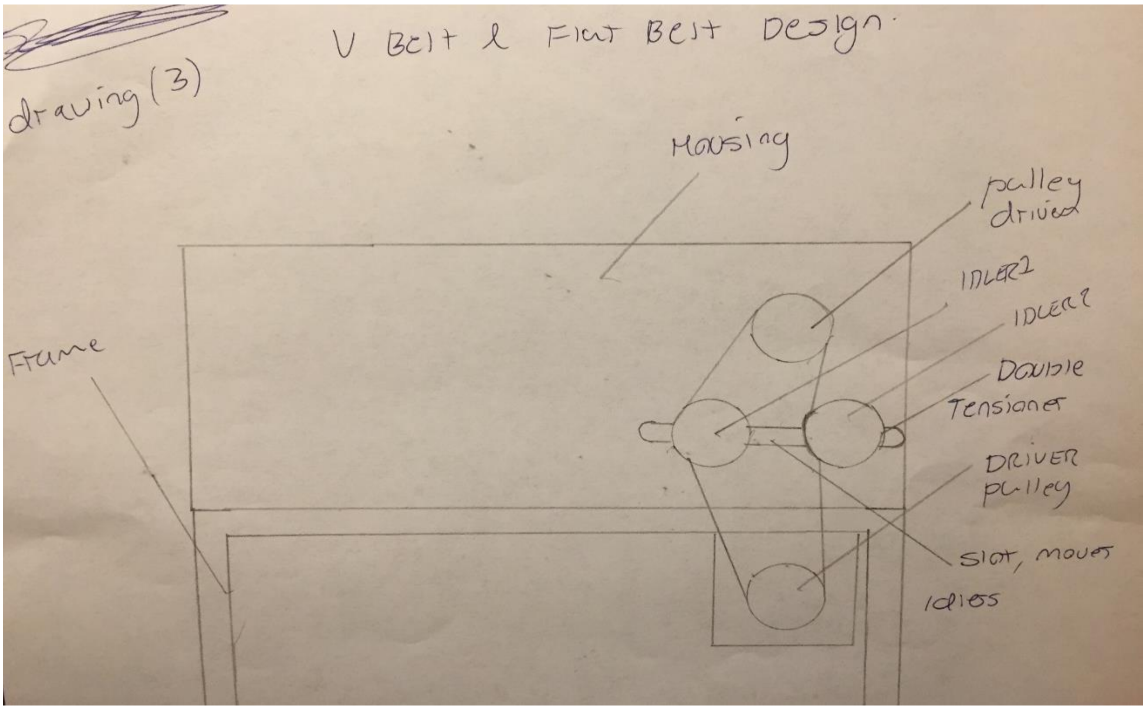


Figure 9 Drawing 3

Drawing 4

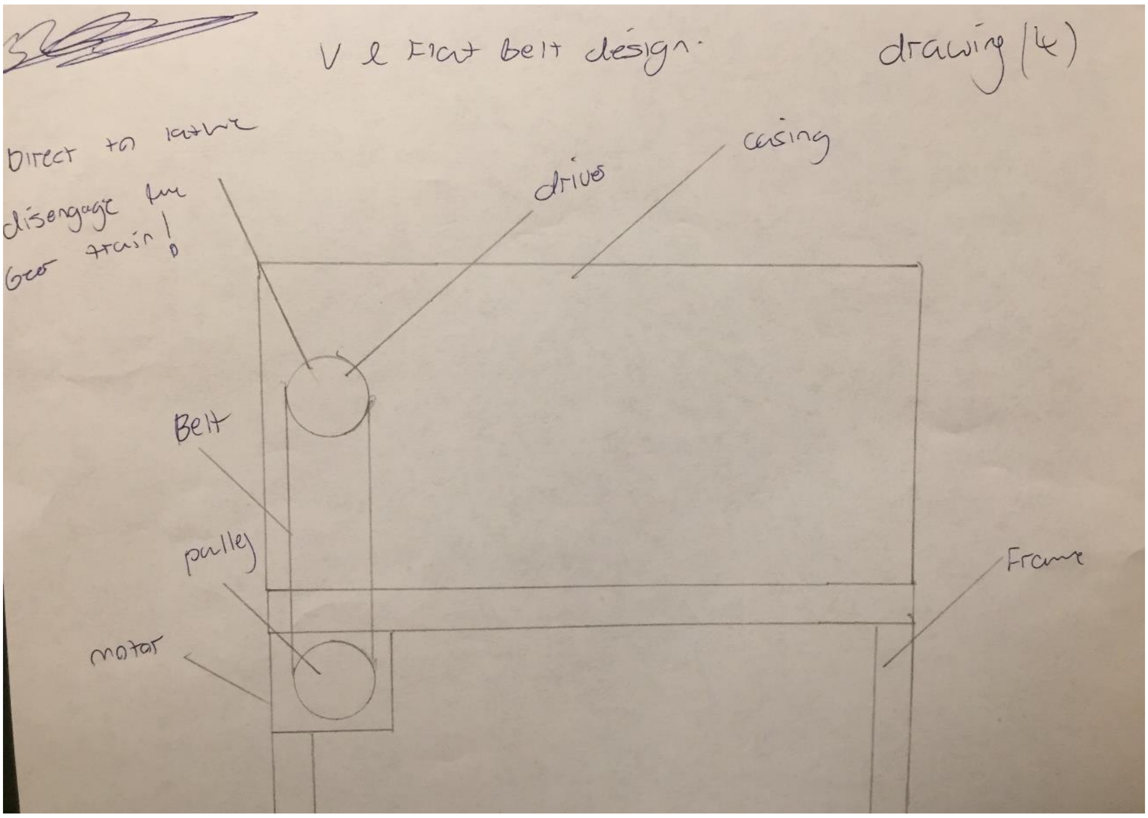


Figure 10 Drawing 4

Decision

After designing four ideas I have narrowed them down to 2 choices.

Drawing 1

The motor to be attached is at its shortest distance, making the belts as short as possible, making it cost effective. The design is health and safety conscious by mounting the motor under the frame of the lathe (protection by placing out of reach).

Drawing 3

Is like drawing 1, however tension idlers are utilised, this keeps a tension on a belt, when a belt is bigger than the pulleys distance, which is common for allowance of belt stretch, and means of fitting the belt. I have included two idlers, the reason is because a 3-phase motor, can turn either clockwise or anticlockwise when energised.

Design idea Conclusion

Initially we will use design 1.

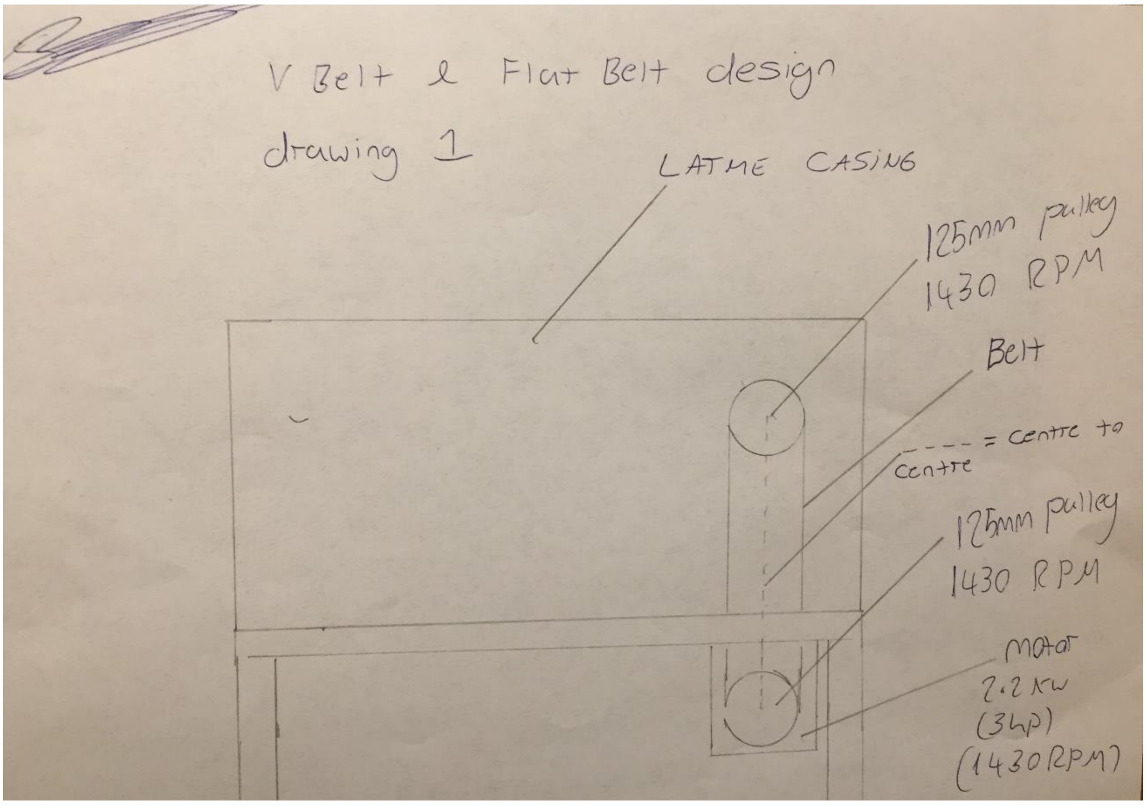


Figure 11 Drawing 1a

Decision

The reason for design 1 is because It is simple, and I can gradually add to it.

To begin the design, we need to position the motor and motor shaft, this gives us a centre distance of 338mm (see Assembly step 3), this is the first thing to obtain, without this nothing can be calculated or designed.

Once the belts were calculated it turned out that we could not buy a belt to suit the length of the Pulleys. This means we need to select bigger sized Belts, and now most of the calculations are now wrong. There are three choices to keep the belts tight without re doing all my work.

- Adjustable Motor
- Tension Idler
- Manufacture Belts to suit.

Designed problem solved

I have decided that an Idler serves a better purpose, it allows for more belt sizes, and belt stretch, which makes it more universal in terms of parts. And calculations are not a major issue for precision. The Lathe is redesigned for final draft, this draft covers all areas to design the pulleys systems.

Final Draft Design

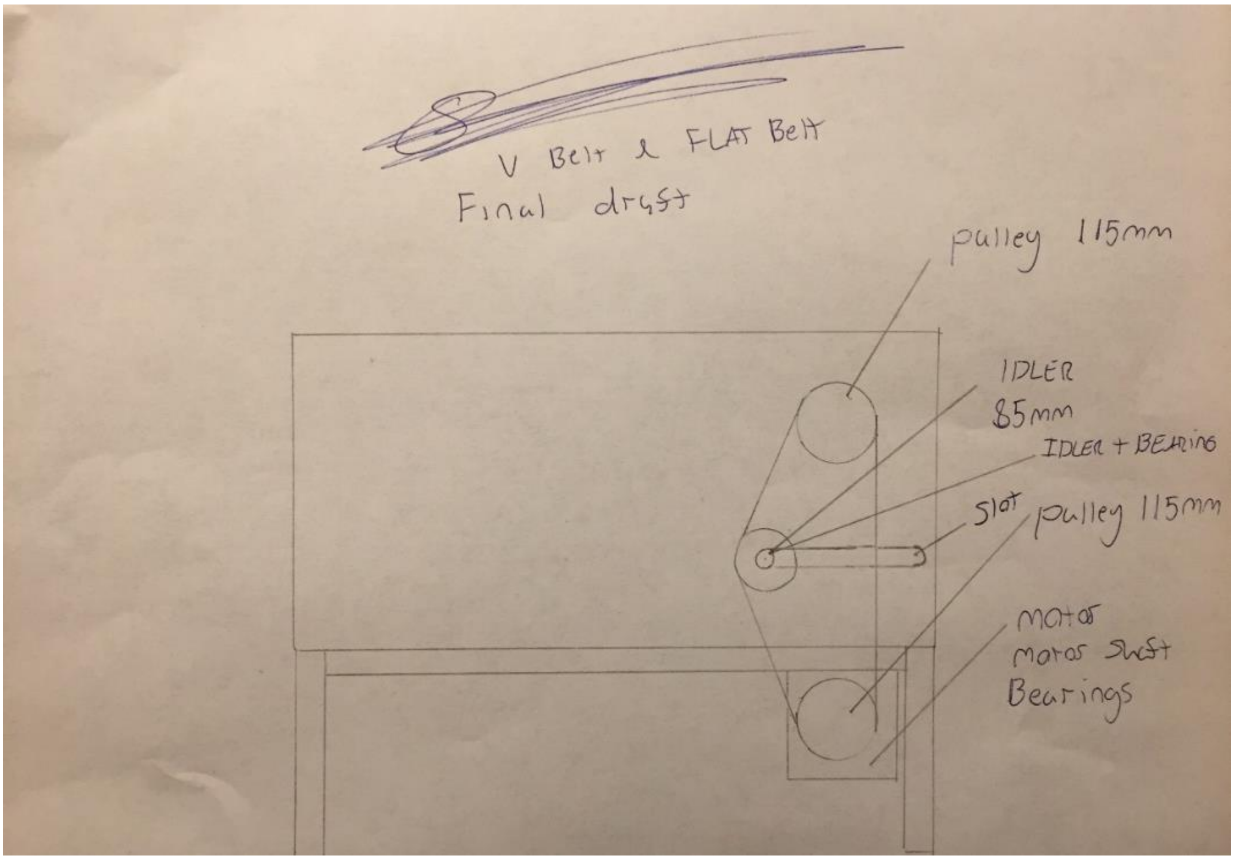


Figure 12 Drawing 5

Final design

Incorporating a tension idler, I made the slot wide, so the idler can move from one side to the other on a tensioned spring, depending on motor direction.

Compare Against Previous Designs

Pugh and Matrix

chart helps to decide if the final draft is the correct method to follow.

Table 24 Pugh and Matrix Design Comparison

Pugh Matrix							
			Solution Alternatives				
Concept Selection Legend Better + Same S Worse - **Key Criteria**	***Importance Rating***	Perfect Pulley System	DESIGN 1	DESIGN 2	DESIGN 3	DESIGN 4	FINAL DRAFT
Cost	**10**	S	-	+	-	-	S
Complexity to Design	**8**	S	S	-	+	-	+
Health and Safety	**10**	S	S	S	S	S	S
RPM/S	**10**	S	S	S	S	S	S
Material Availability	**6**	S	S	S	S	S	S
Achievability	**8**	S	S	-	-	-	S
Time Taken	**7**	S	S	-	-	-	+
Personal Interest	**8**	S	S	S	S	S	S
Dimensions	**5**	S	S	S	S	S	+
Functionality	**10**	S	S	S	S	S	S
		Sum of Positives	0	1	1	0	3
		Sum of Negatives	1	3	3	4	0
		Sum of Sames	9	6	6	6	7
		TOTALS	**-1**	**-2**	**-2**	**-4**	**3**

Conclusion

Final Draft design is a suitable idea, and an achievable in ability to carry out about to SolidWorks.

Belt Selection

Belt Size and Belt Choice

Belt dimensions and classification dictate the dimensions of the Pulleys.

Justification for Design

Reason why I'm choosing the same size pulleys and same Length belts is because I want to compare the V and a Flat Belts, I am choosing the same surface area as justification, the difference between the Belts will be the power transmitted, torque tensions and cost, some of the factors which conclude in the method best suited for a 2.2kw lathe, and which system to add the braking mechanism to.

V Belt and Flat Belt Design

To determine the Pulley, Belts, materials and Dimensions, we need to consider the design of the Lathe, giving the specification of 1430 RPM and 2.2 kw, the other constant is the service factor, the service factor for this lathe has a factor of 1.4, category 3, 16hr days. It is a class A system, which means the RPM is greater than 700.

	SERVICE FACTOR					
	CLASS A			CLASS B		
	• AC Motor: Asynchronous, • Synchronous, Normal Torque DC • Motor: Shunt wound • Internal combustion engines: Multicylinders speed > 700 rpm			• AC Motor: Vector control, • Reluctance Motor, High Torque • DC Motor: Compound wound • Internal combustion engines: Turbines speed < 700 rpm		
	Duty cycle category					
	Intermittent service	Normal service	Continuous service	Intermittent service	Normal service	Continuous service
	< 8 hours daily	8 to 16 hours	> 16 hours daily	< 8 hours daily	8 to 16 hours	> 16 hours daily
Category 1: LIGHT DUTY DRIVES Blowers, Vacuum cleaners, Magnetic agitators, Domestic gadgets, Fans and pumps up to 7,5 kW	1,0	1,1	1,2	1,1	1,2	1,3
Category 2: MEDIUM DUTY DRIVES Machine tools, Generators, Rotary pumps, Belt conveyors, Laundry machinery	1,1	1,2	1,3	1,2	1,3	1,4
Category 3: MEDIUM-HIGH DUTY DRIVES Concrete and Woodwork machinery, Axial fans, Brick machinery	1,2	1,3	1,4	1,3	1,4	1,5
Category 4: HIGH DUTY DRIVES Hammer mills, Elevators, Paper machinery, Piston pumps, Dredging pumps, Granulators	1,3	1,4	1,5	1,4	1,5	1,6
Category 5: EXTRA DUTY DRIVES Excavators, Mixers, Ballgrinding mills, Winches	1,4	1,5	1,6	1,5	1,6	1,8

Figure 13 Service Factor Chart

(Megadynegroup.com, 2017)

V belt design is equal to sf x kw = 1.4 x 2.2 = 3.1kw

We know the design power and RPM for the Belt.

RPM x horsepower chart

Charts shows the class of belt at 3.1 Kw.

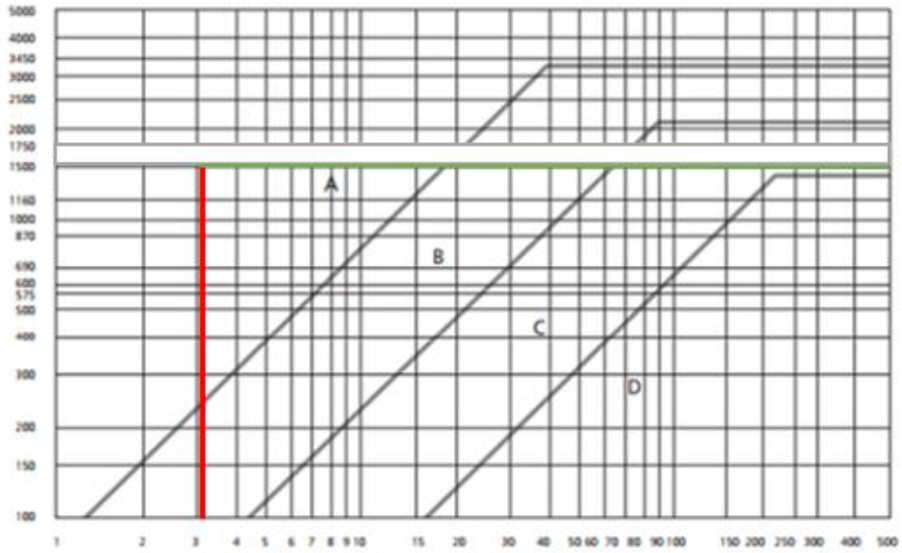


Figure 14 RPM v Design Power Chart

(Anon, 2017)

Charts show that for an RPM of 1430 and a design power 3.1kw, the belt class is a type A.

V Belt Dimension Selection Chart

Cross Section A (A Class)

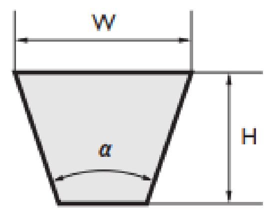
Cross Section	W	H	α	Features
A	12.5	9.0	40°	
B	16.5	11.0	40°	
C	22.0	14.0	40°	
D	31.5	19.0	40°	

Figure 15 V Belt Selection Chart

(Anon, 2017)

Cross Section A Type V Belt Dimensions

Table 25 Cross Section A Type V Belt Dimensions

W =12.5mm
Bottom width = 5mm
H = 9mm
Angle = 40 degree
Angle length = 10mm x 2 = 20mm of contact

Belt Specification

Table 26 Belt Specification

Initial belt size
1037.1mm
Effective belt size = 980mm
V Belt choice = 1040mm (dictated by Flat Belt Length)

Belt Choice

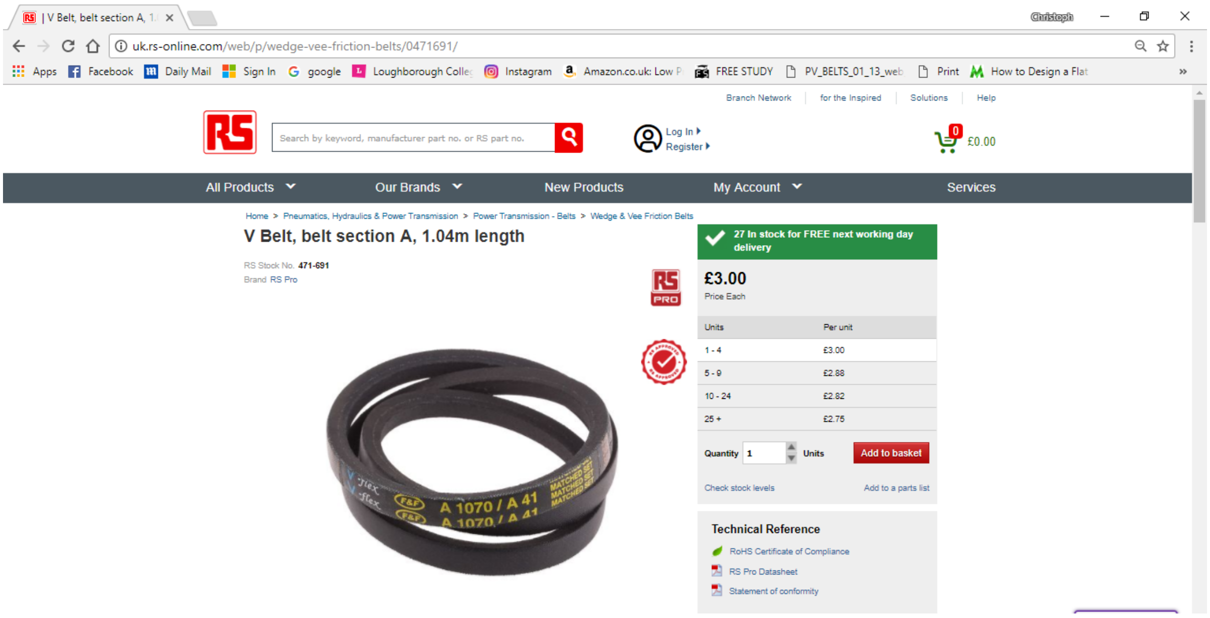
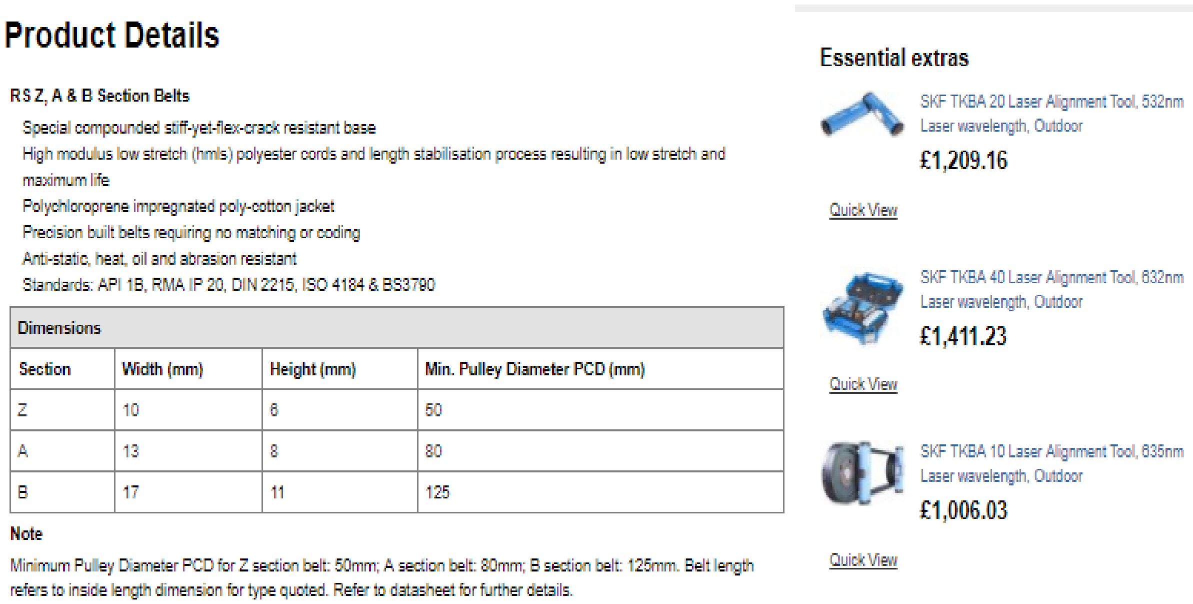


Figure 16 RS Components V Belt



Product Details

RS Z, A & B Section Belts

Special compounded stiff-yet-flex-crack resistant base
High modulus low stretch (hmls) polyester cords and length stabilisation process resulting in low stretch and maximum life
Polychloroprene impregnated poly-cotton jacket
Precision built belts requiring no matching or coding
Anti-static, heat, oil and abrasion resistant
Standards: API 1B, RMA IP 20, DIN 2215, ISO 4184 & BS3790

Dimensions			
Section	Width (mm)	Height (mm)	Min. Pulley Diameter PCD (mm)
Z	10	6	50
A	13	8	80
B	17	11	125

Note

Minimum Pulley Diameter PCD for Z section belt: 50mm; A section belt: 80mm; B section belt: 125mm. Belt length refers to inside length dimension for type quoted. Refer to datasheet for further details.

Essential extras

SKF TKBA 20 Laser Alignment Tool, 532nm Laser wavelength, Outdoor
£1,209.16
Quick View

SKF TKBA 40 Laser Alignment Tool, 632nm Laser wavelength, Outdoor
£1,411.23
Quick View

SKF TKBA 10 Laser Alignment Tool, 635nm Laser wavelength, Outdoor
£1,006.03
Quick View

Figure 17 RS Components Product Details

(V Belt, 2017)Belt found at RS Components. This also gives Data specification to the size of pulley required and material (PET) Rubber and ISO and BS standards.

Flat belt Dimension

The flat belt will have the same surface area as the V belt for comparison reasons.

Table 27 Flat belt Dimension

Initial belt size = 1037.1mm
Effective belt = 1030mm
Belt choice = 1040mm (dictates V Belt Length)
W = 20mm (dictated by V Belt contact area)

Belt Speed Determines number of Plies.

Table (v) – Standard Flat Belt Widths in mm

3 Plies	4 Plies	5 Plies	6 Plies	8 Plies
25	25	76	100	200
32	32	90	112	250
40	40	100	125	305
44	44	112	152	355
50	50	125	180	400
63	63	152	200	

Figure 18 Number of Plies

(Sankararaj, 2017)

Conclusion

3 Plies thick, is rated at 25 m/s, however my belt is only 8.6m/s

25/8.6 = 2.9 rounded to 3

1 plie = 1mm

8.6m/s = 1mm plie

H = 1mm

Flat Belt Choice

This Data gives information to material selection, cost, tolerances and standards.

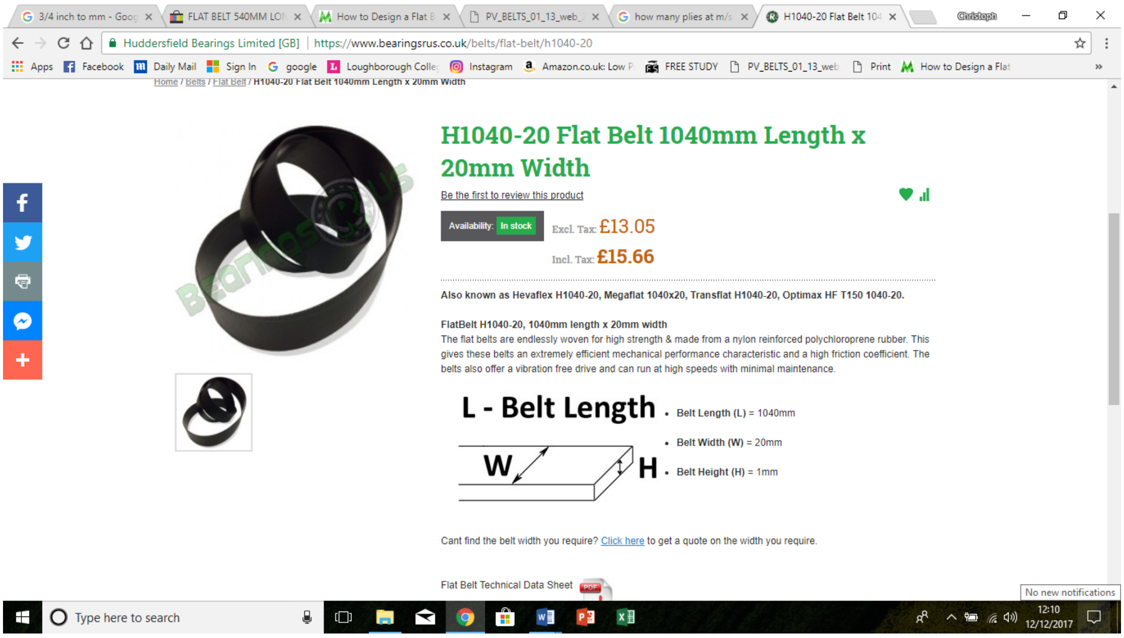


Figure 19 Bearings are us, Flat Belt

(Bearingsrus.co.uk, 2017)

Design

Now we have both belts dimensions, this gives us the pulleys dimensions, we can now begin to design the pulleys using SolidWorks. Utilising the Specification area of this report and Hand Calculations to complete the design.

Pulley Design

Both pulley systems for flat and V Belts are 115mm diameter pitch, which exceeds the minimum pulley diameter specified at RS Components, but not by much, as cost is a factor.

(V Belt, 2017)

Both sets have 30mm diameter hole central for motor shaft and driven shaft, and each have 6 holes central to the outside diameter and circumference of the centre hole, each has a diameter of 30mm, and is used to keep the cost of the materials down and retain the strength in design.

Idler Design

V belt and flat belt idler have 85 mm diameter pitch

(V Belt, 2017)

Flat belt outside diameter 90mm (4mm lip)

V belt outside diameter 95mm (1mm lip)

CAD Example

Design in SolidWorks

Sketched pulleys

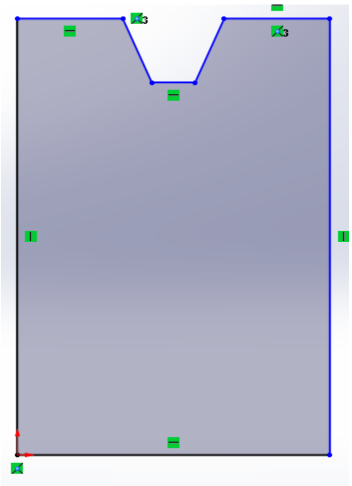


Figure 20 V Belt CAD design

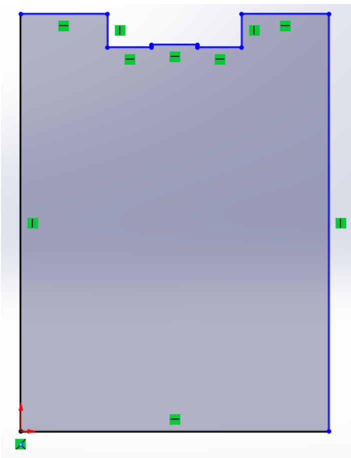


Figure 21 Flat Belt CAD Design

Extrude 360

Flat Belt Pulley Example, See SolidWorks for all designs and video motion.

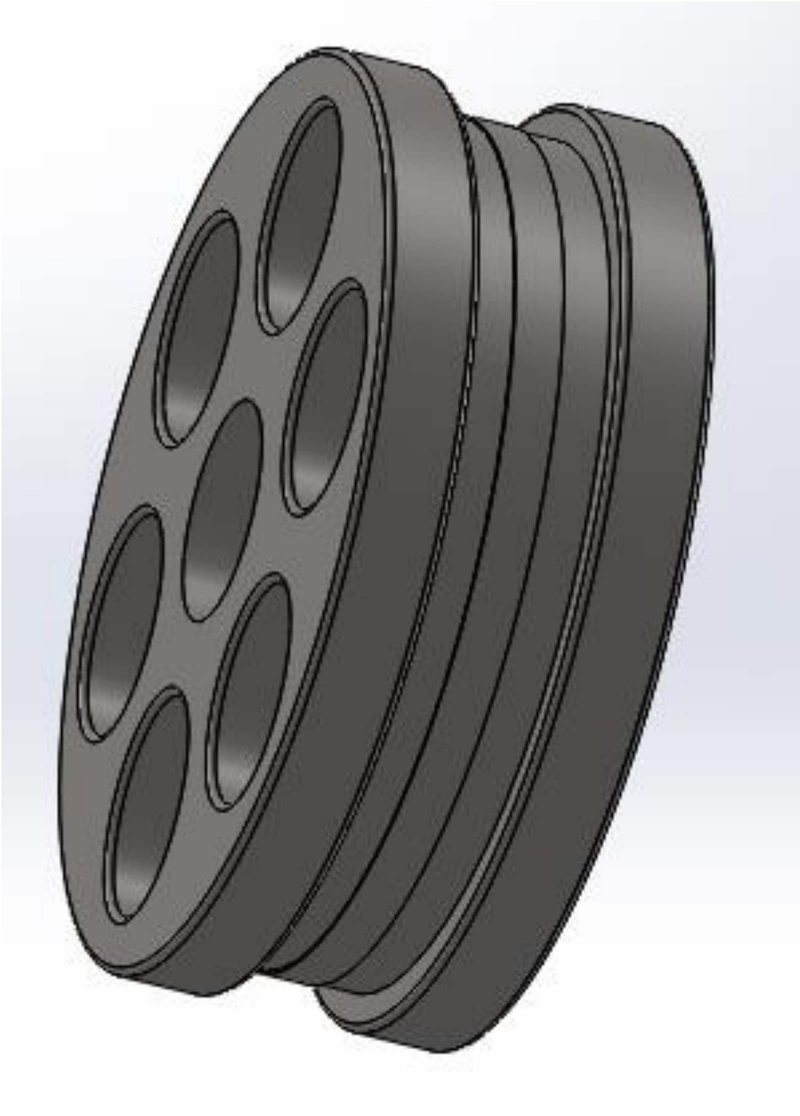


Figure 22 Extrude Pulley Picture

Select materials for pulleys and idlers.

Material selected, Ductile Iron, 65 45 12 it is cost effective, sustainable and effective in its duty's. (see Material Selection)

After all parts are made in SolidWorks they can be assembled to the lathe. (see Assembly Process), a video of both flat and V Belts have been Provided alongside three 2D drawings showing the tolerances in CAD.

Design Selection Pugh Matrix Chart

Table 28 Design Choice, Pugh and Matrix

Concept Selection Legend

Better	+
Same	S
Worse	-

Key Criteria	*Importance Rating*	Perfect Pulley System	V BELT	FLAT BELT
Cost	**10**	S	S	+
Complexity to Design	**8**	S	+	S
Health and Safety	**10**	S	S	S
Rpm/S	**10**	S	S	S
Material Availability	**6**	S	S	S
Achievability	**8**	S	+	S
Time Taken	**7**	S	+	S
Personal Interest	**8**	S	+	S
Power Transmission	**10**	S	+	-
Torque	**10**	S	+	-
Dimensions	**5**	S	+	S
Functionality	**10**	S	S	S
		Sum of Positives	7	1
		Sum of Negatives	0	2
		Sum of Sames	5	9
		TOTAL	**7**	**-1**

Conclusion

V Belt Pulley system outperforms the Flat Belt.

Add Braking Mechanism

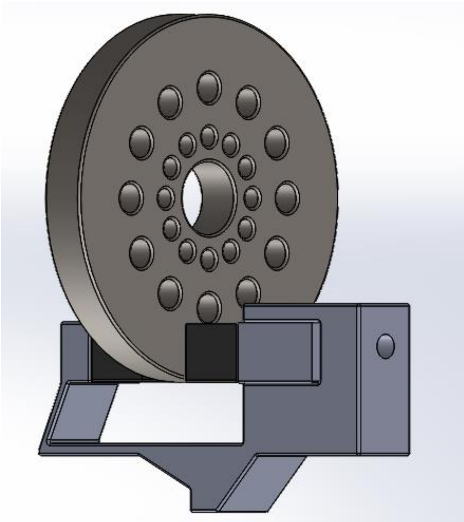


Figure 23 Brake and Calliper

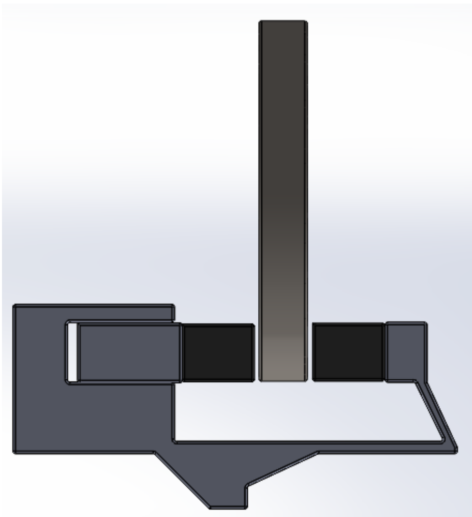


Figure 24 Front View Brake and Calliper

I designed a brake mechanism for the Lathe design. It consists of the following parts.

- Brake Disc (175mm Diameter)
- Calliper (see SolidWorks)
- Brake Pads (2 x 25 x 25 x 25 mm)
- Piston (Hydraulic)

A Hydraulic brake will be added, the methodology, a brake disc, this will be attached to the motor drive shaft. To work the brake, we use a foot peddle that acts as a switch, but is also a safety feature of the lathe, a foot on the peddle, switches on power, foot off the peddle turns the power off, upon turning the power off the piston is filled with hydraulic fluid which pushes on the brake pads causing friction on the brake disc which slows the machine. This is achieved by using a contactor switch that recognises that the switch to the lathe peddle has been released, sends a signal to the hydraulic pump operate which then carries out the work.

Finished design

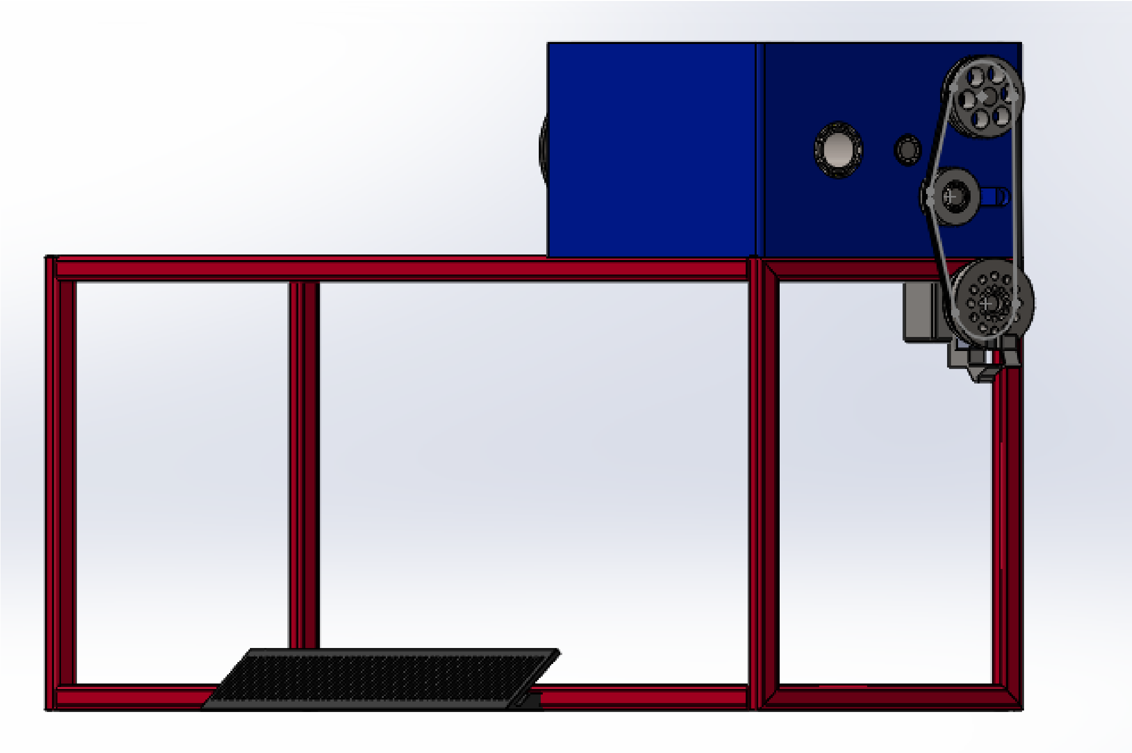


Figure 25 V Belt Lathe with Foot Peddle, Calliper and Brake Disc

The Run down should be less than the start up.

(defined in European Standards as ten seconds or less)

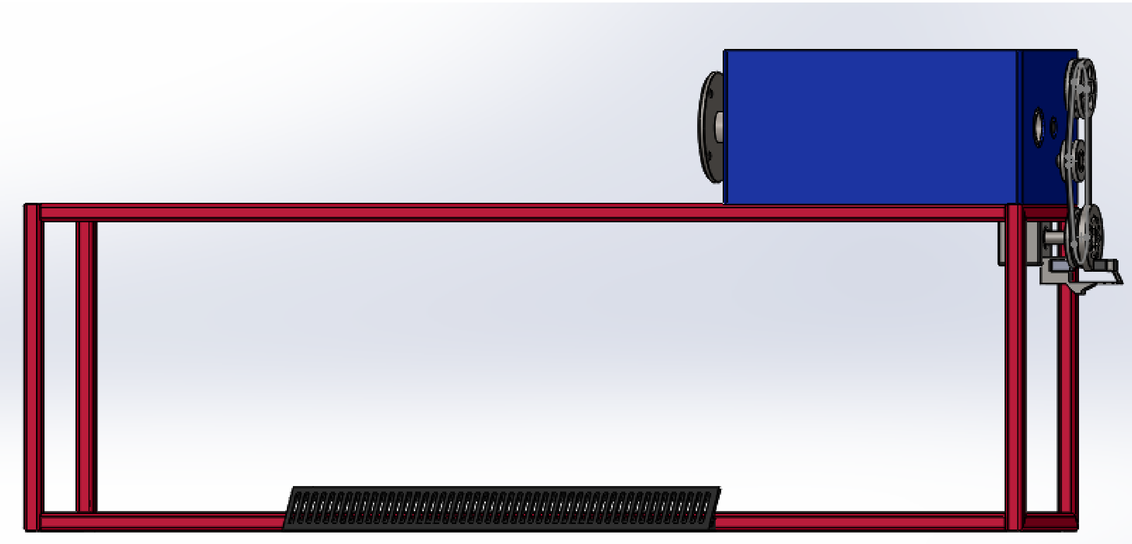


Figure 26 Angled View of V Belt Lathe

2D drawing of Brake, pads, and disc

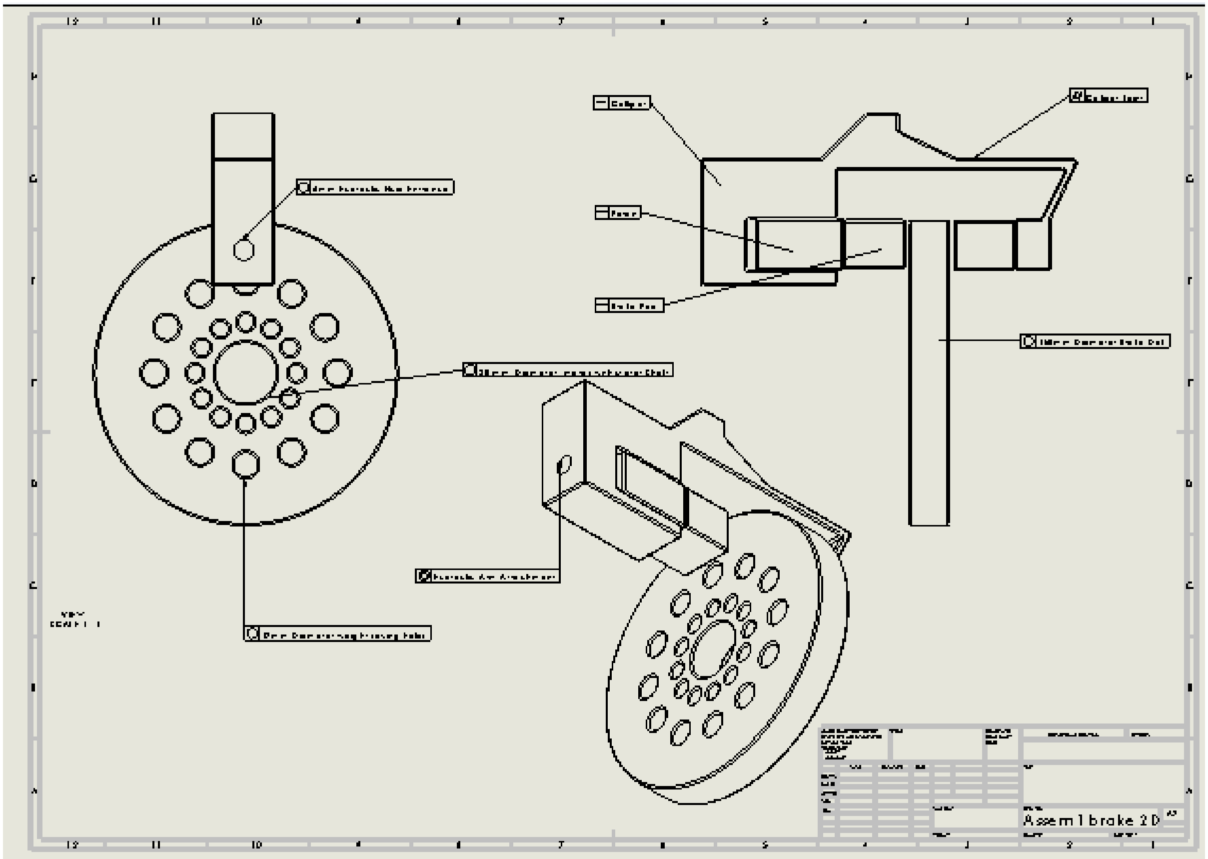


Figure 27 2D Drawing of Brake and Calliper

Assembly Process

For V belt, and Flat belts, the Assembly process is the same other than Idler positions, to keep it short I have mixed the two assemblies throughout this process using SolidWorks.

Step 1

Mate bearings with Idler and motor, using Coincident mating type, this allows idler to rotate about the bearings.

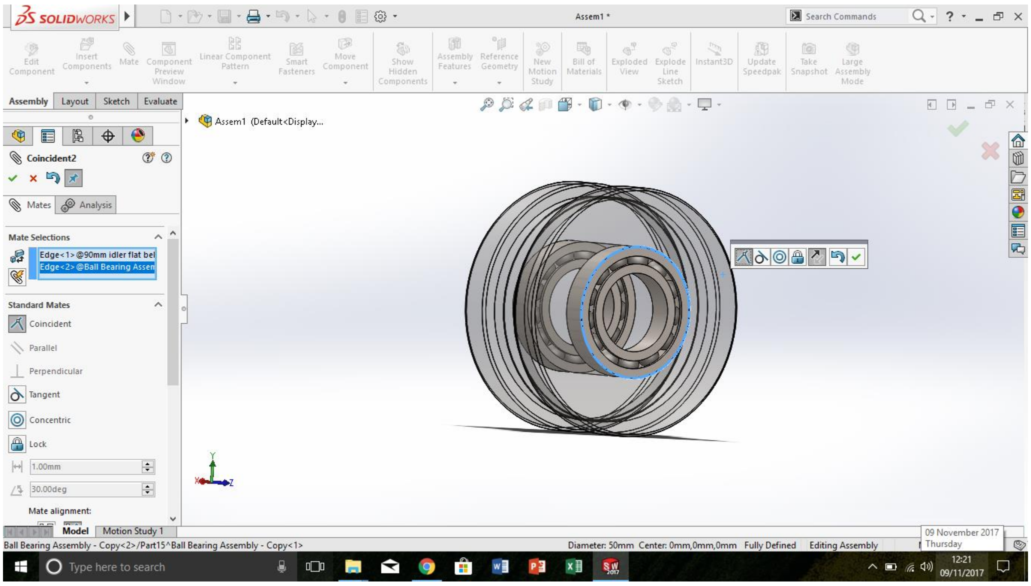


Figure 28 Assembly Step 1

Step 2

Position motor

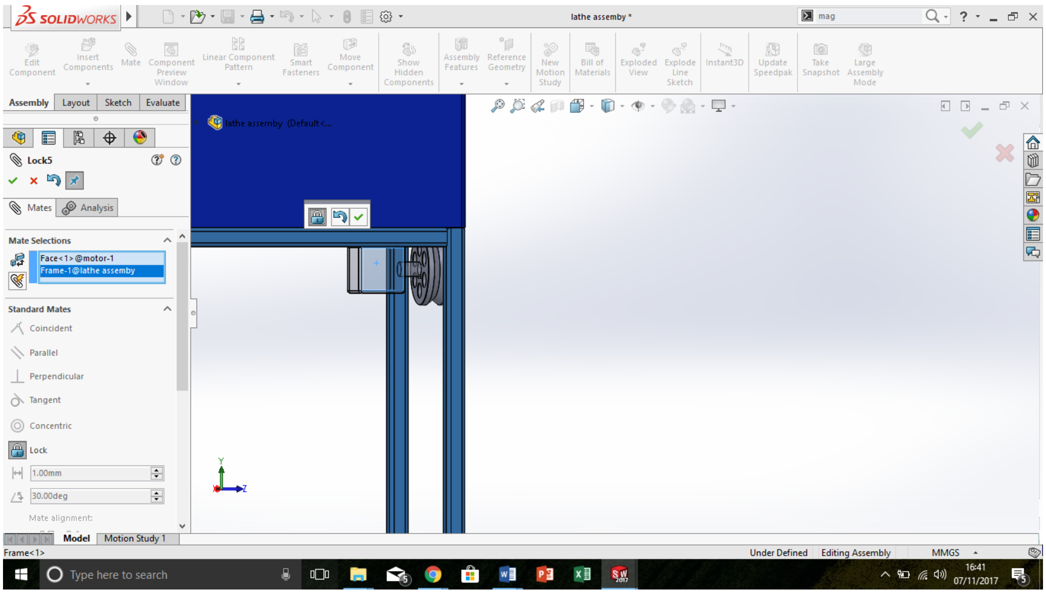


Figure 29 Assembly Step

Step 3

Measure the centre distance, and check motor and drive shaft to the Lathe are in-line. Add parts to use for Assembly.

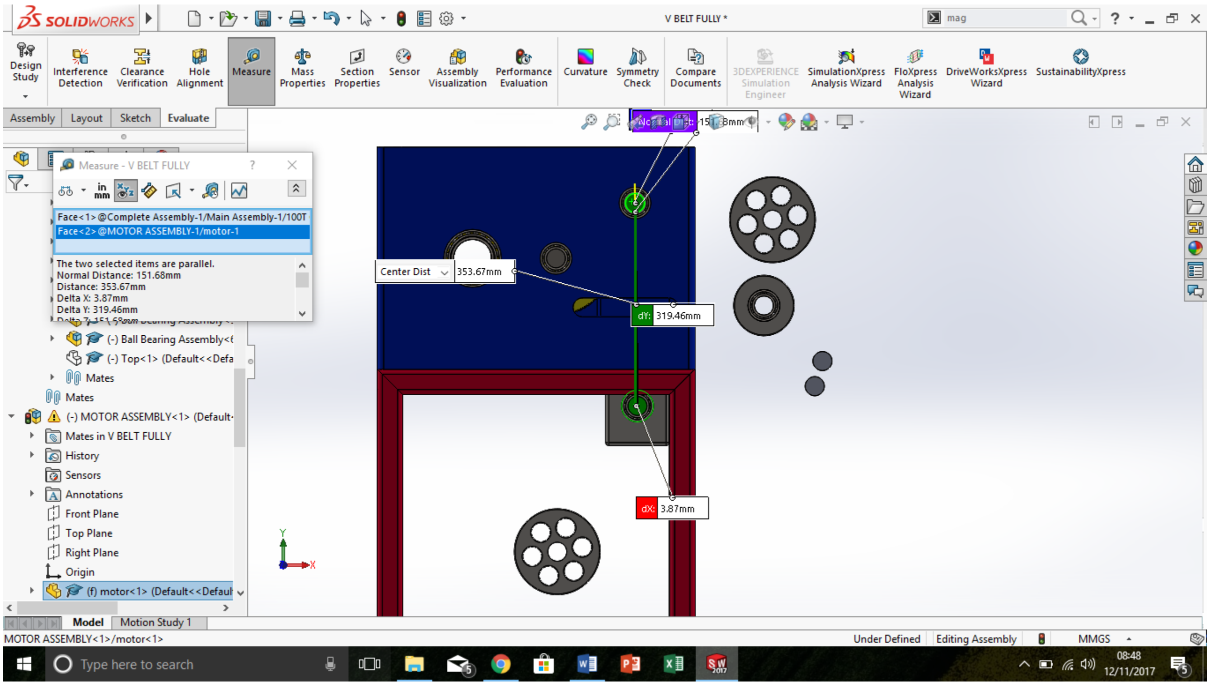


Figure 30 Assembly Step 3

Step 4

Lock the motor to the body of the gearbox, we are not welding as a real motor wold come with holes for nut and bolts so its adaptable in positioning.

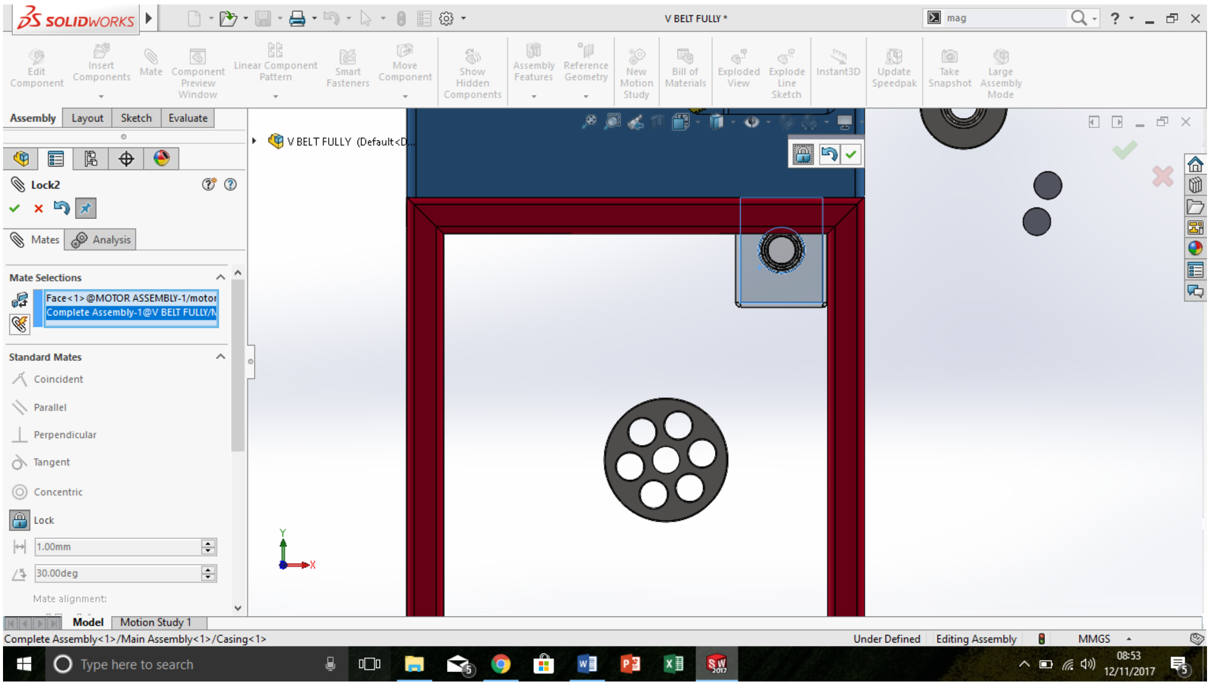


Figure 31 Assembly Step 4

Step 5

Insert shaft for motor Coincident.

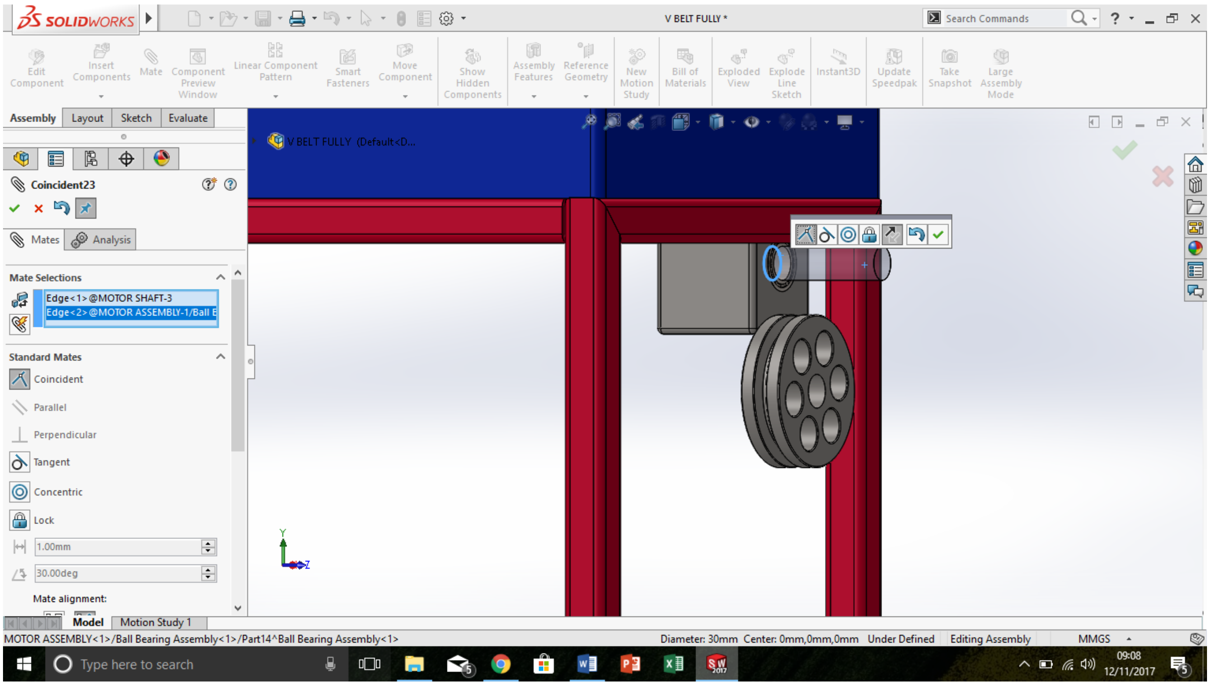


Figure 32 Assembly Step 5

Step 6

Insert shaft for Idler, Tangent mate.

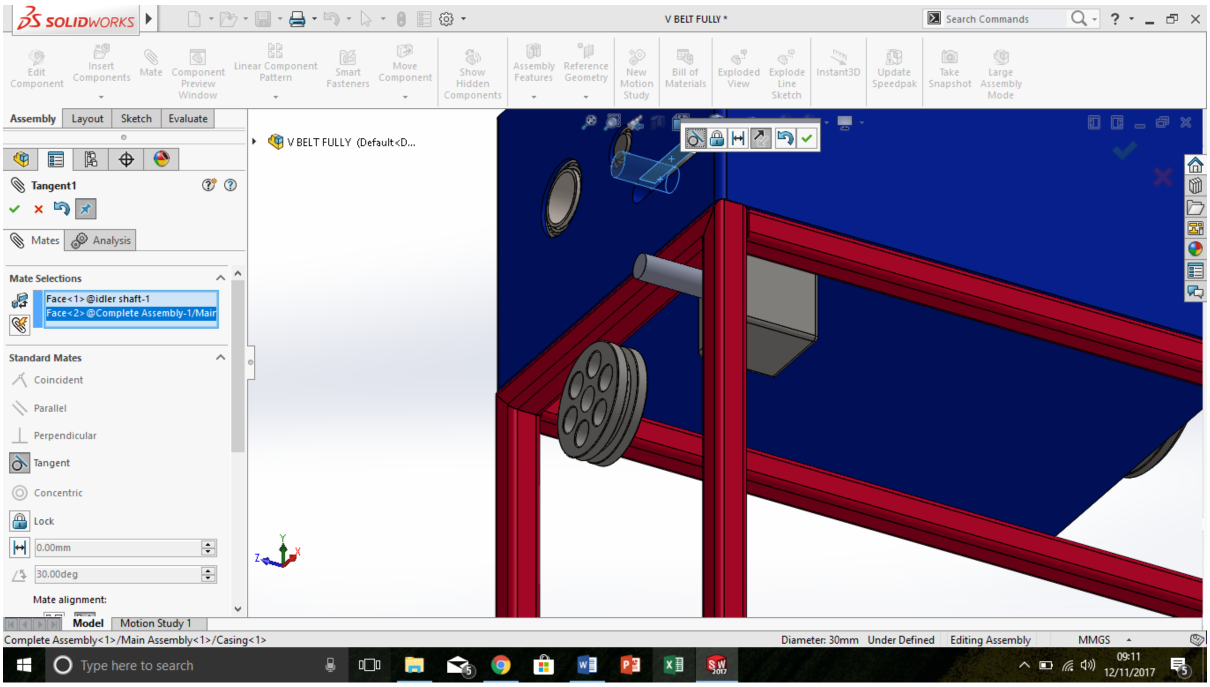


Figure 33 Assembly Step 6

Step 7

Mate pulley to edge of shaft using coincident mate.

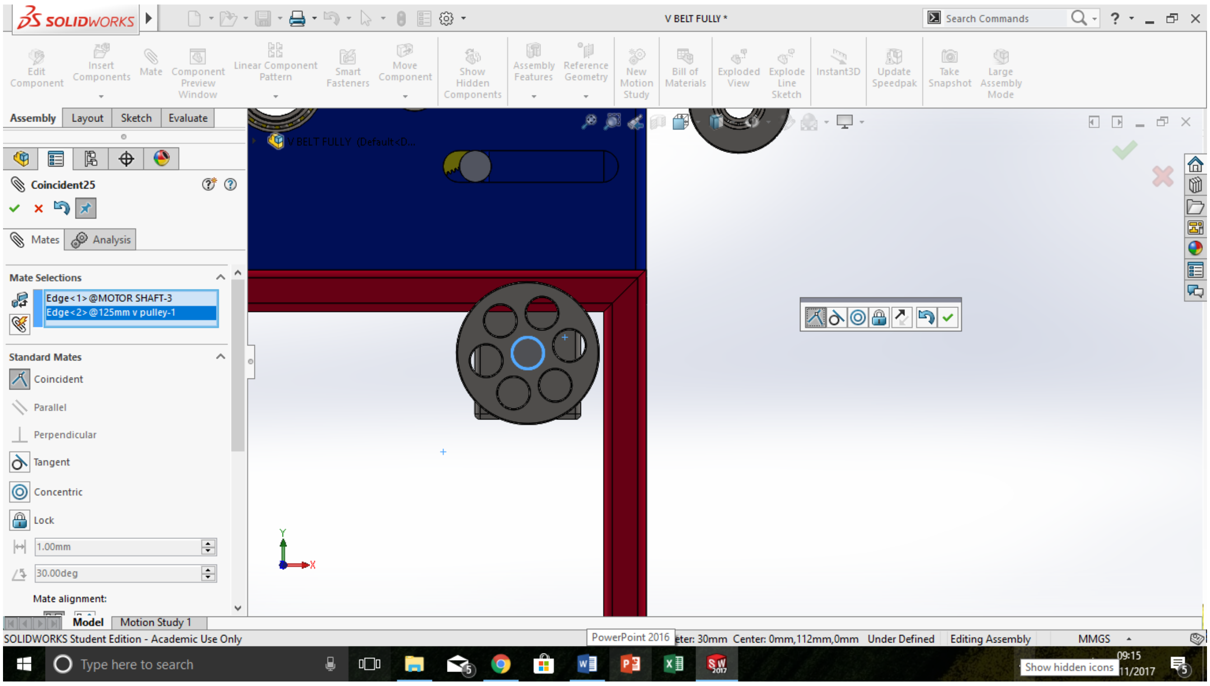


Figure 34 Assembly Step 7a

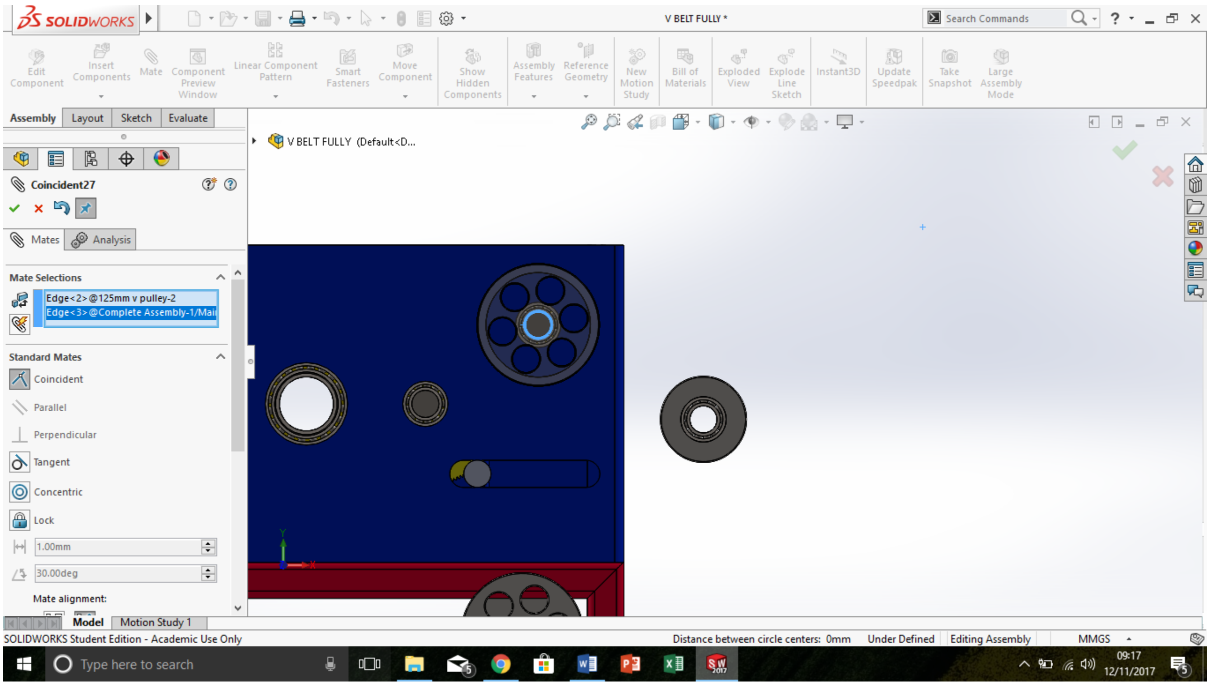


Figure 35 Assembly Step 7b

Step 8

Position Idler to Tension Shaft, central to pulleys as pulleys are the same size.

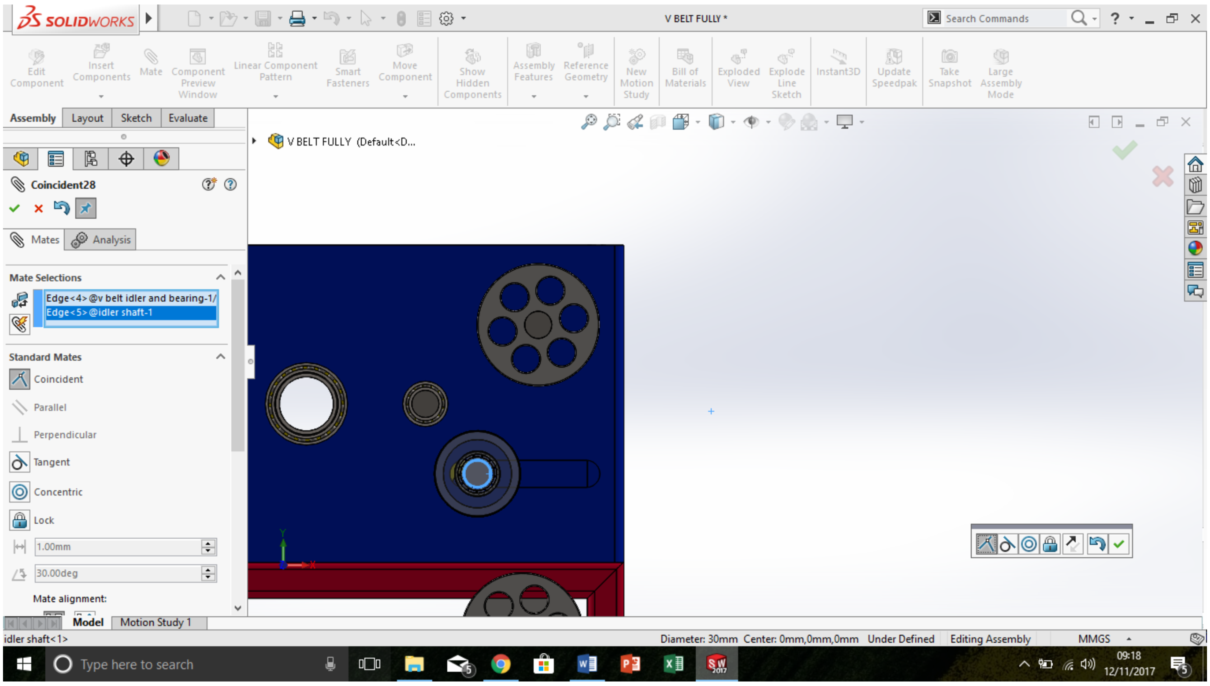


Figure 36 Assembly Step 8

Step 9

Line up pulleys, to be within 3mm accuracy, if components alter, reposition and fix, then select belt from Assembly features.

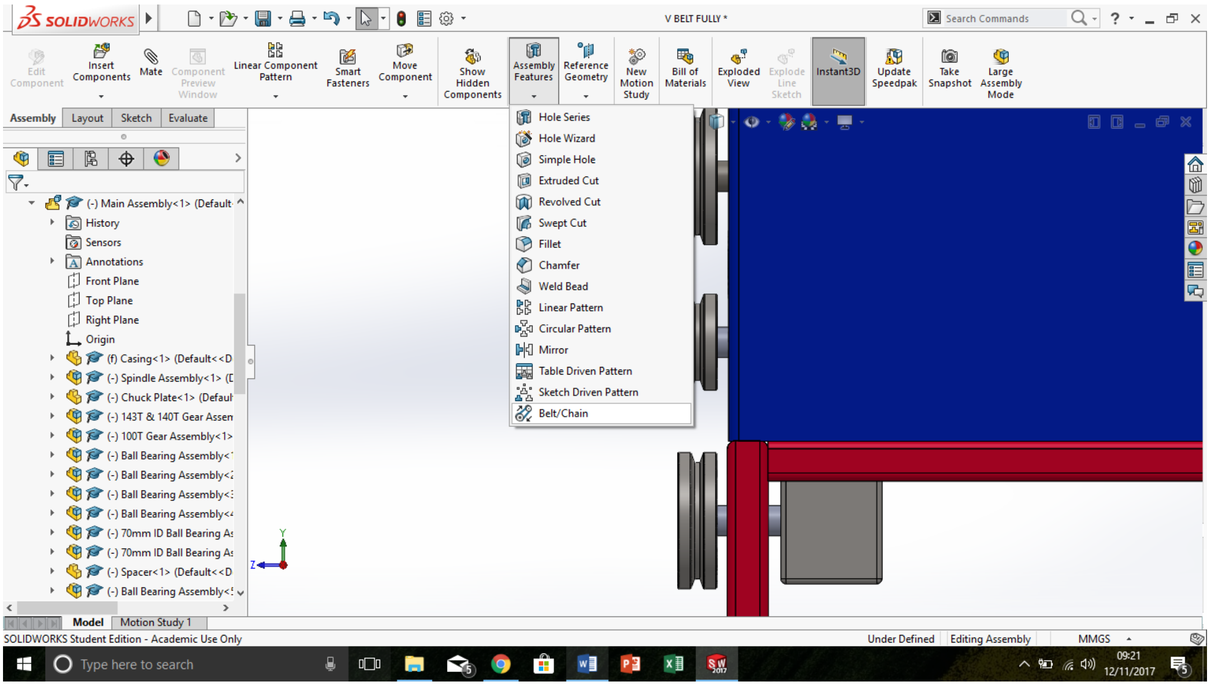


Figure 37 Assembly Step 9

Step 10

Click on centre of pulleys, or where belt is to be positioned, and then click the Idler last, select the direction for the Idler.

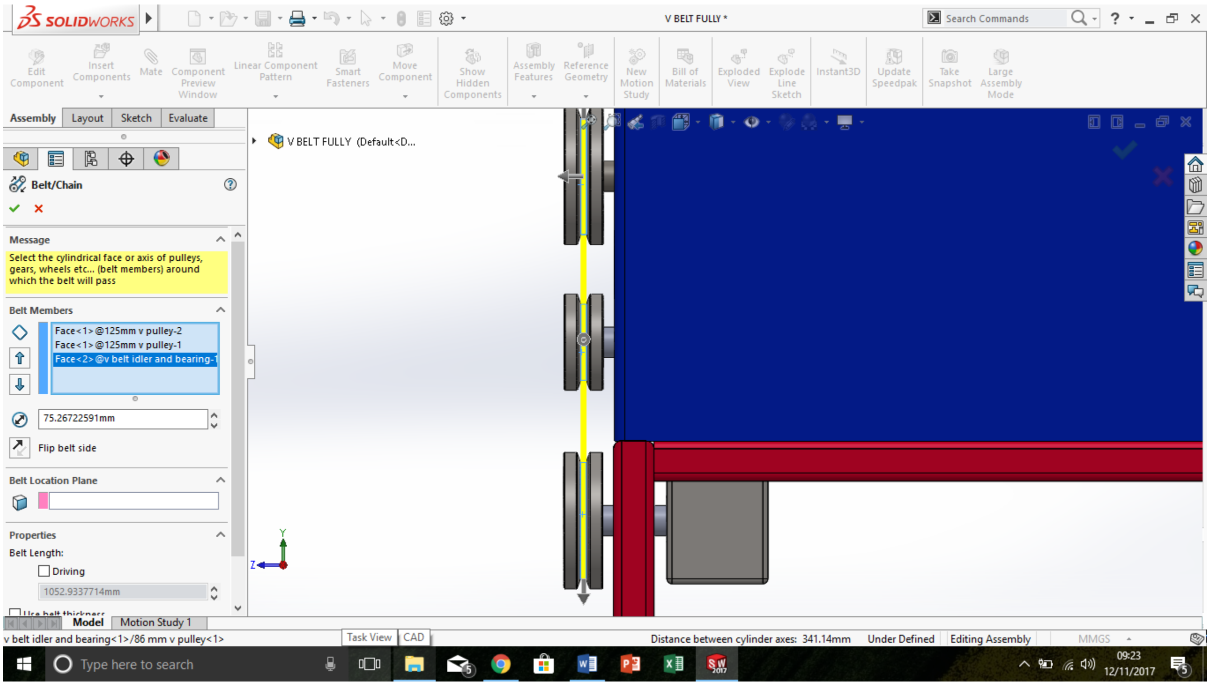


Figure 38 Assembly Step 10

Step 11

Make belt part and manipulate belt length to suit. (1050mm in this case as the belt has stretched) V belt, minimum contact angle 120 degree. (see Appendix).

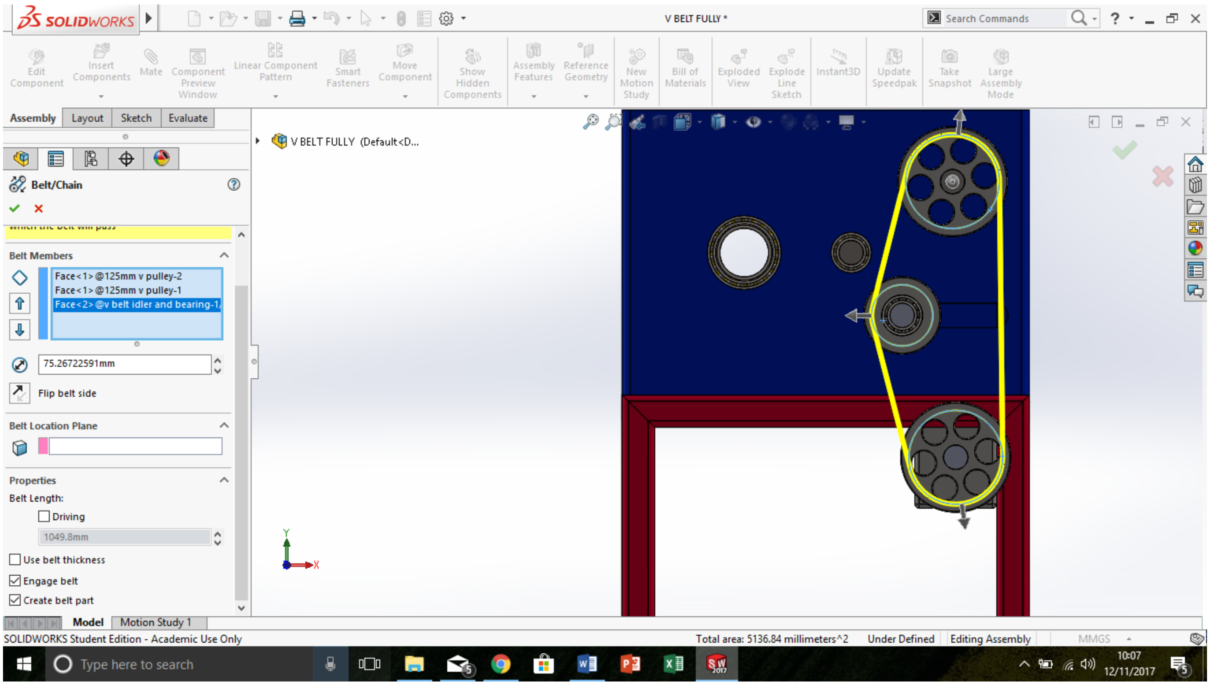


Figure 39 Assembly Step 11a

Flat Belt, position opposite to V Belt, as angle of contact for a flat belt cannot be less than 180 degrees before slip occurs. (see Appendix)

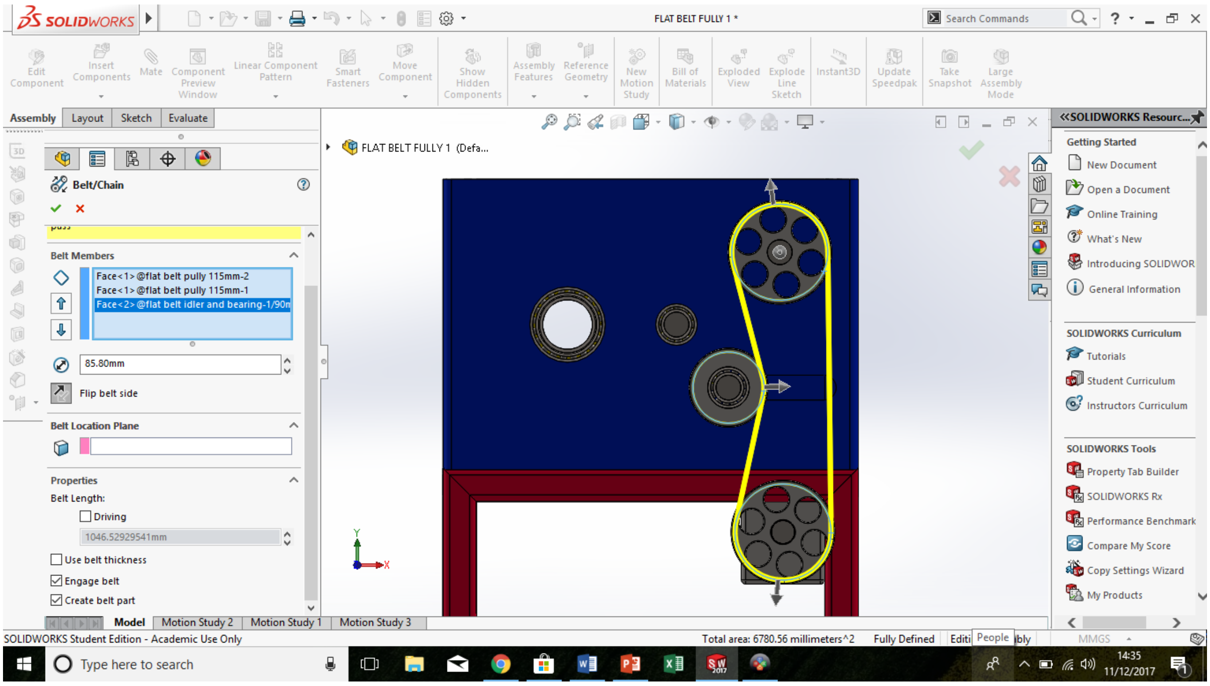


Figure 40 Assembly Step 11b

Step 12

Iscolate belt part, draw the shape of the pulley around the pitch, choose a point of which to start, for v belt as it does not touch the pulley surface. It has a gap distance of 1mm.

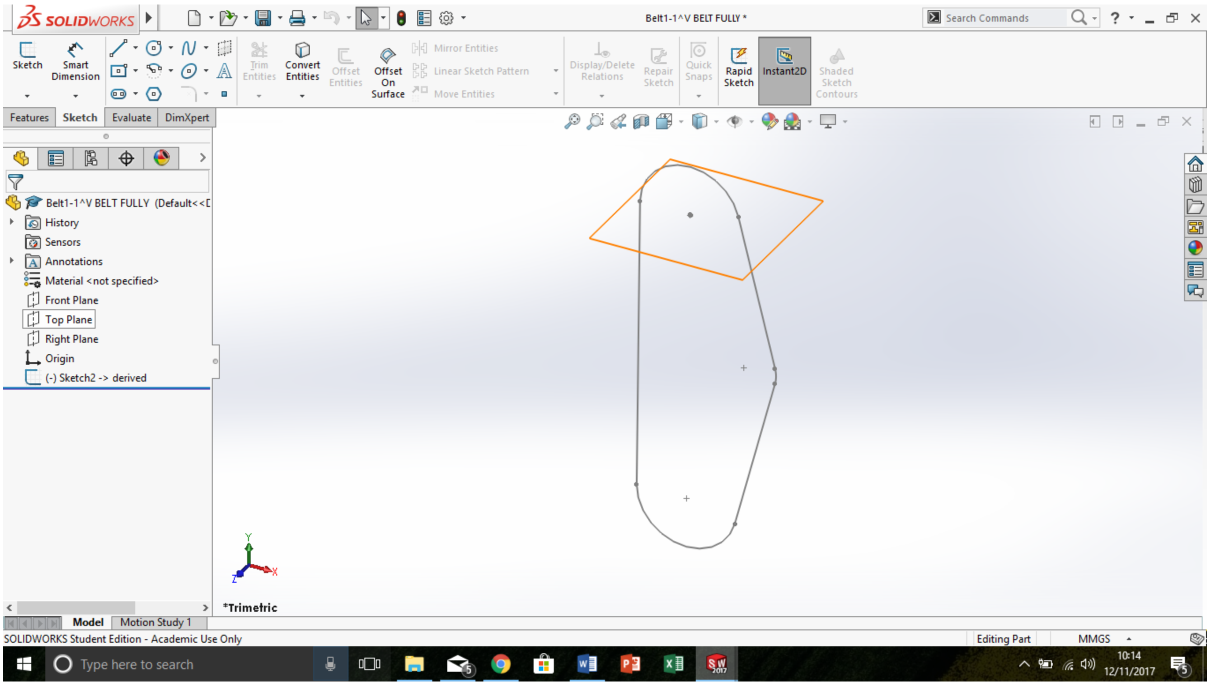


Figure 41 Assembly Step 12a

Select Geometry.

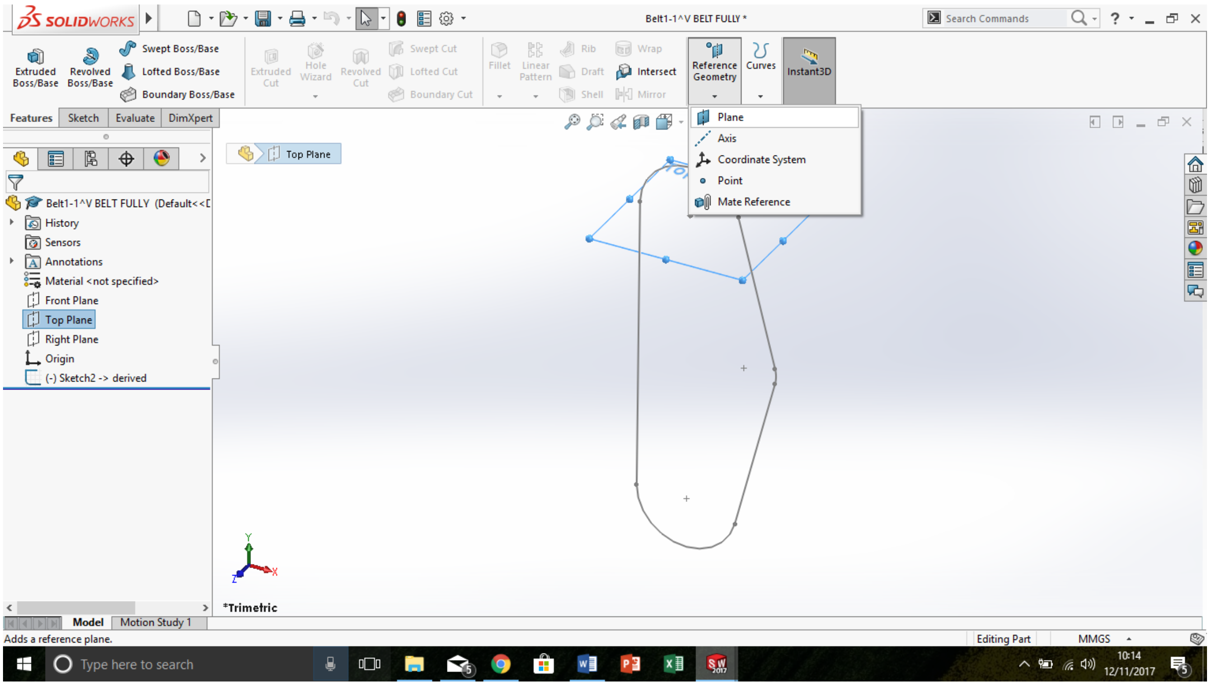


Figure 42 Assembly Step 12b

Click and add point.

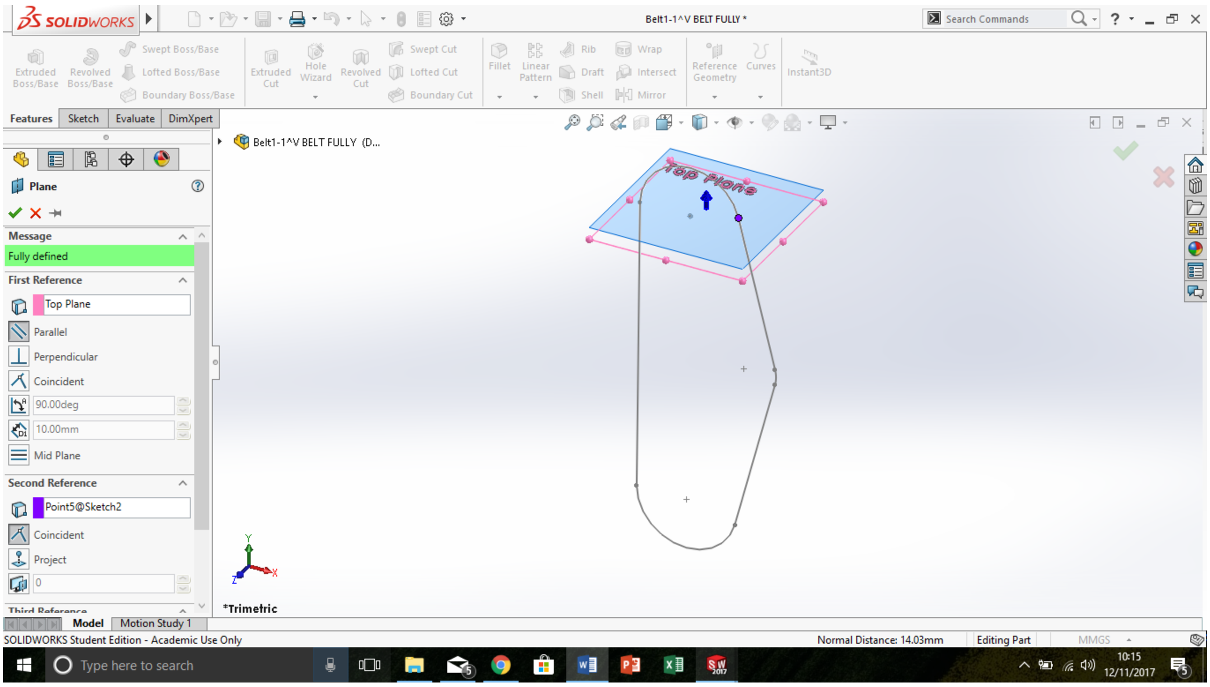


Figure 43 Assembly Step 12c

Normalise.

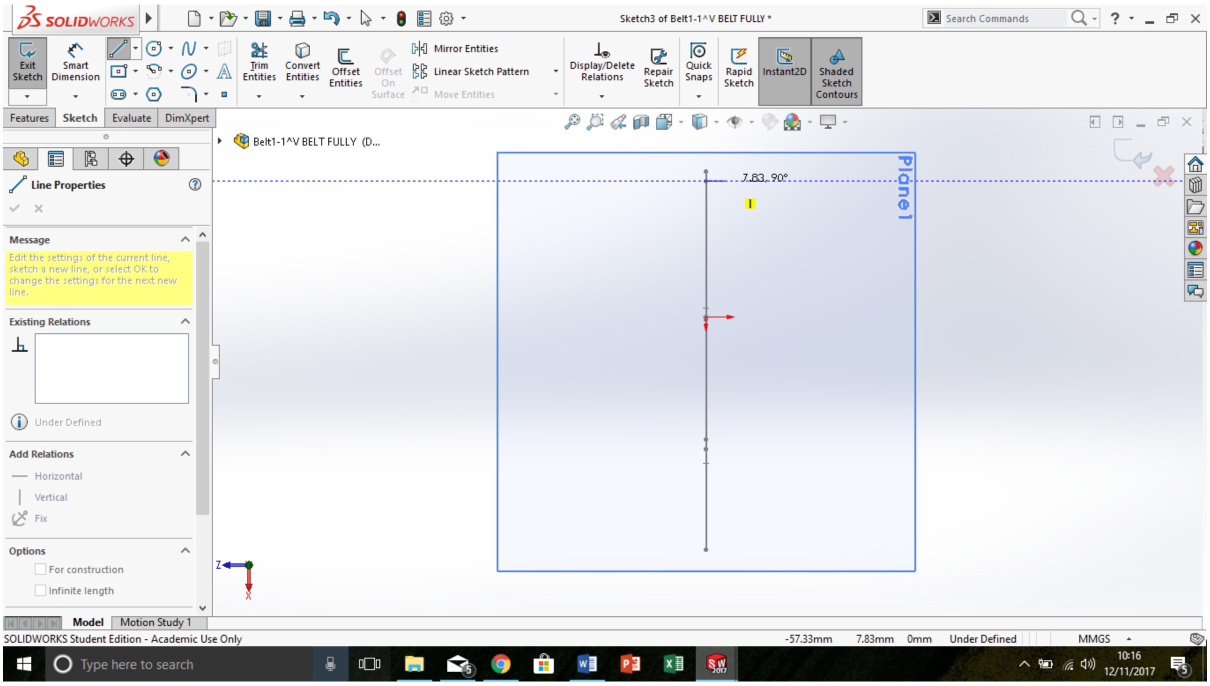


Figure 44 Assembly Step 12d

Obtain a good view.

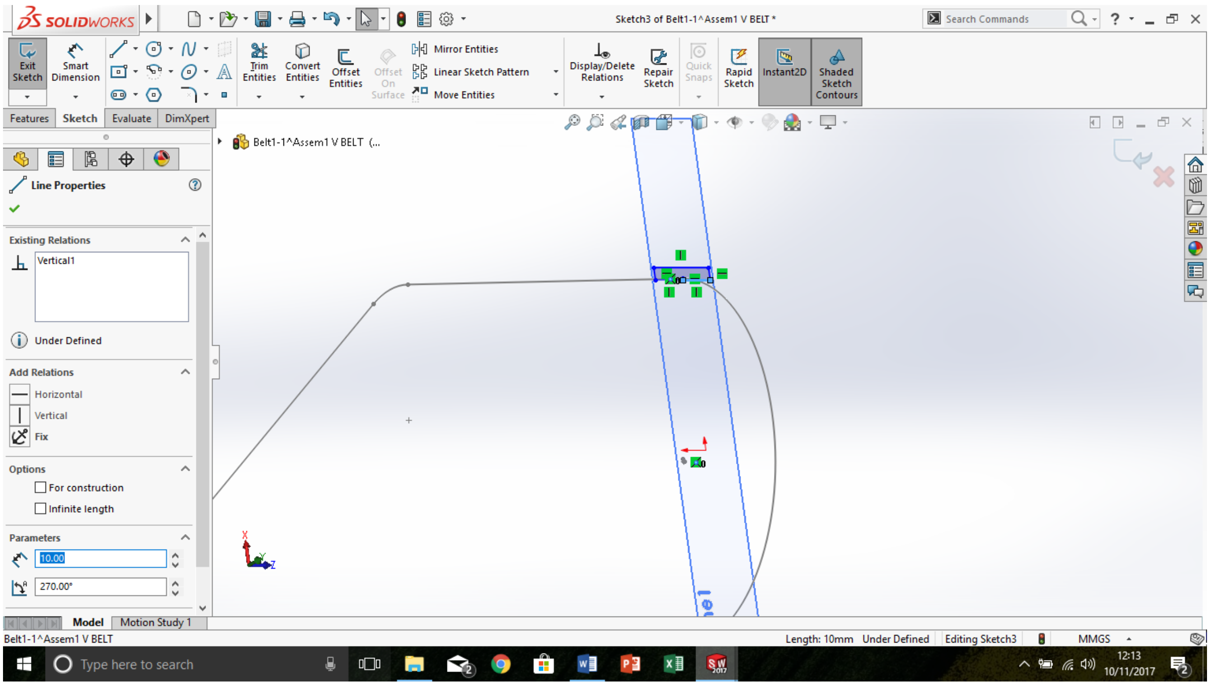


Figure 45 Assembly Step 12e

Sketch belt.

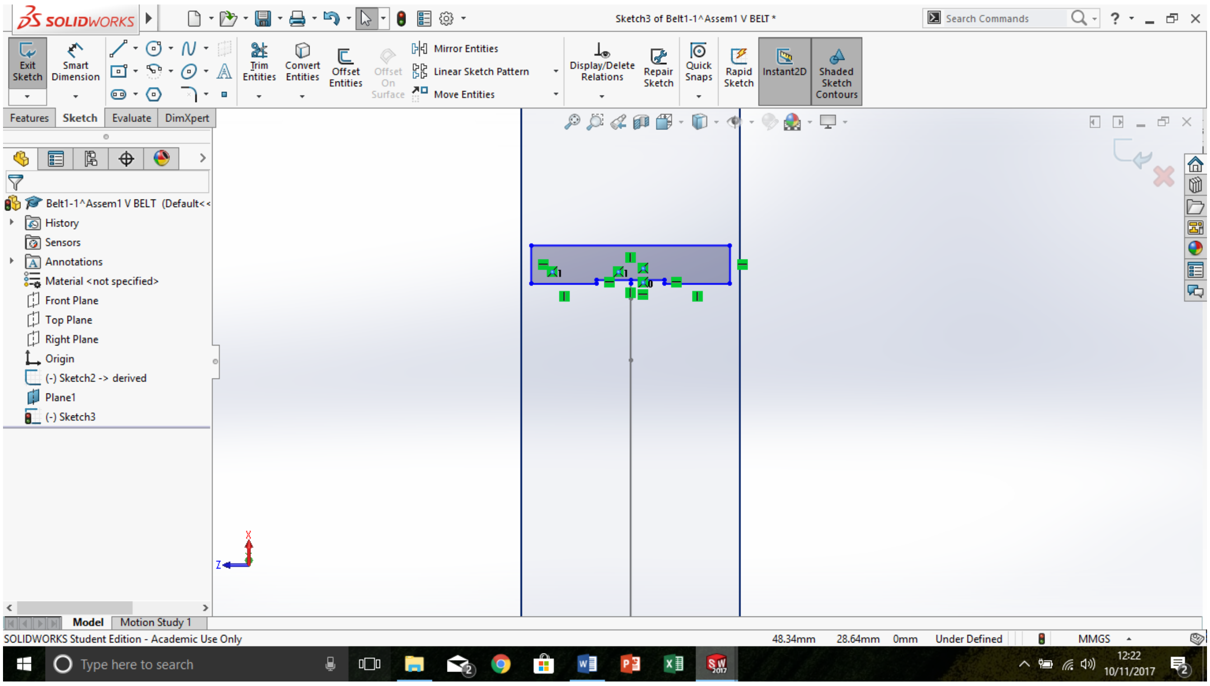


Figure 46 Assembly Step 12f

Step 13

Use bose sweep, hightligh the surfaces of both belt dimensions and the belts pitch length. Press enter.

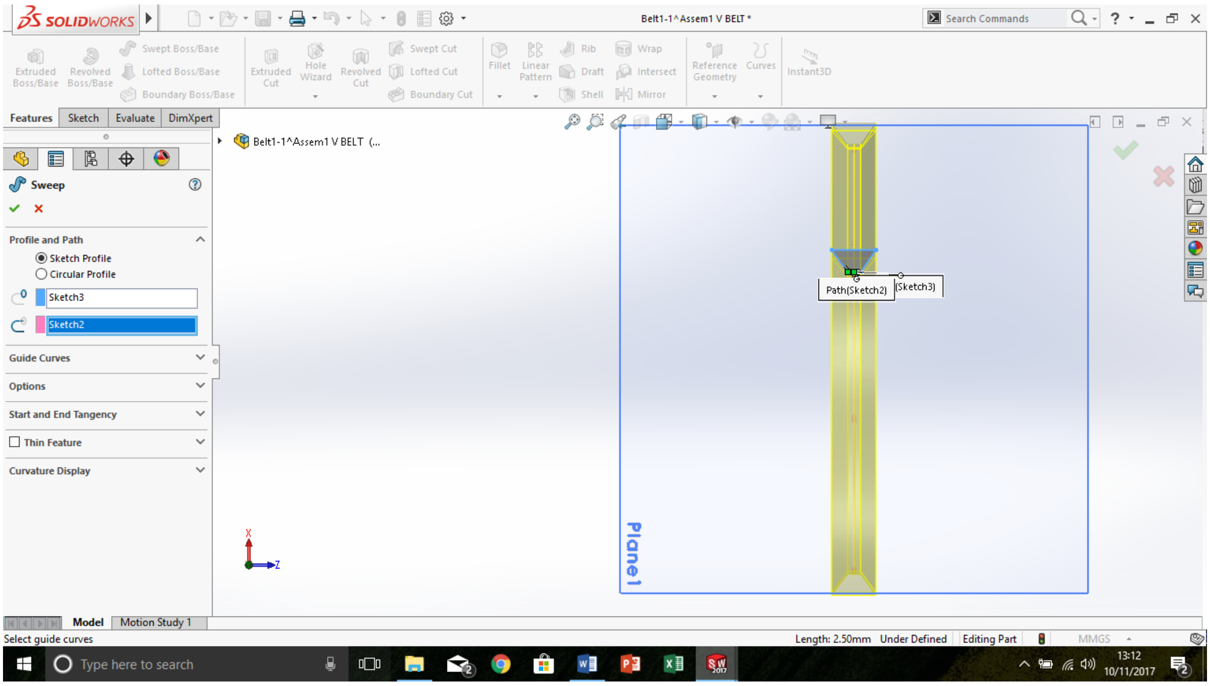


Figure 47 Assembly Step 13a

Check view, press enter.

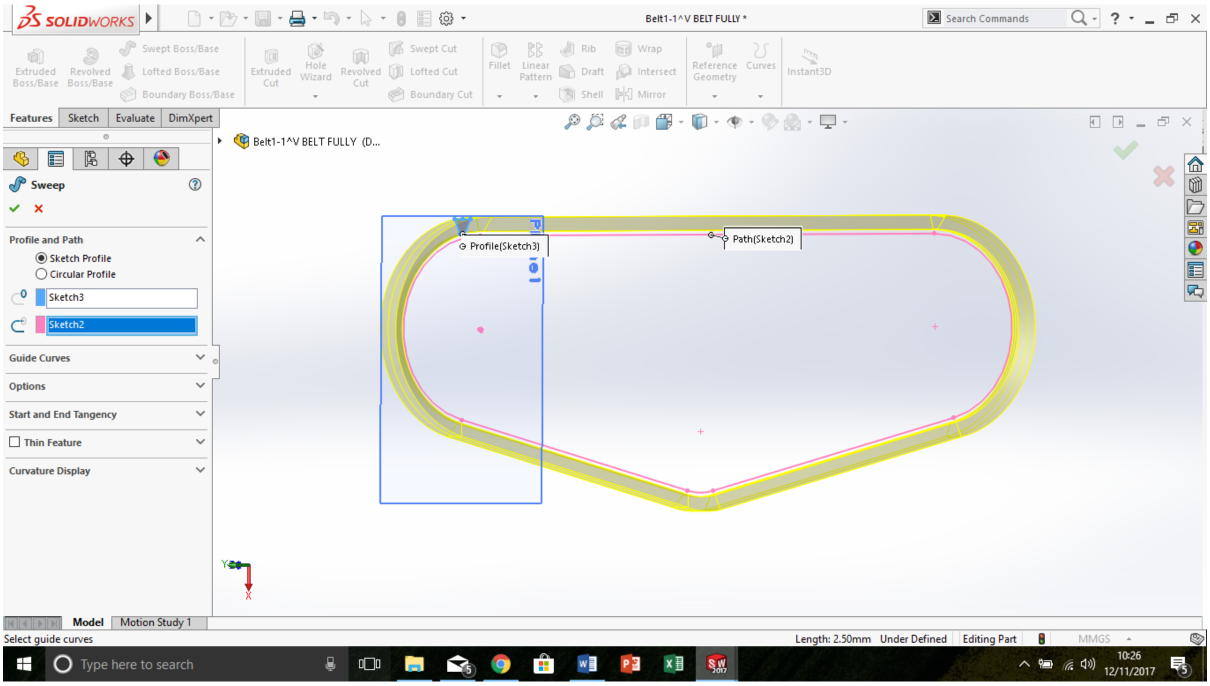


Figure 48 Assembly Step 13b

Step 14

Create belt, for V belt check the distance line in blue to maintain the gap. As a V belts base should not touch base with the pulley.

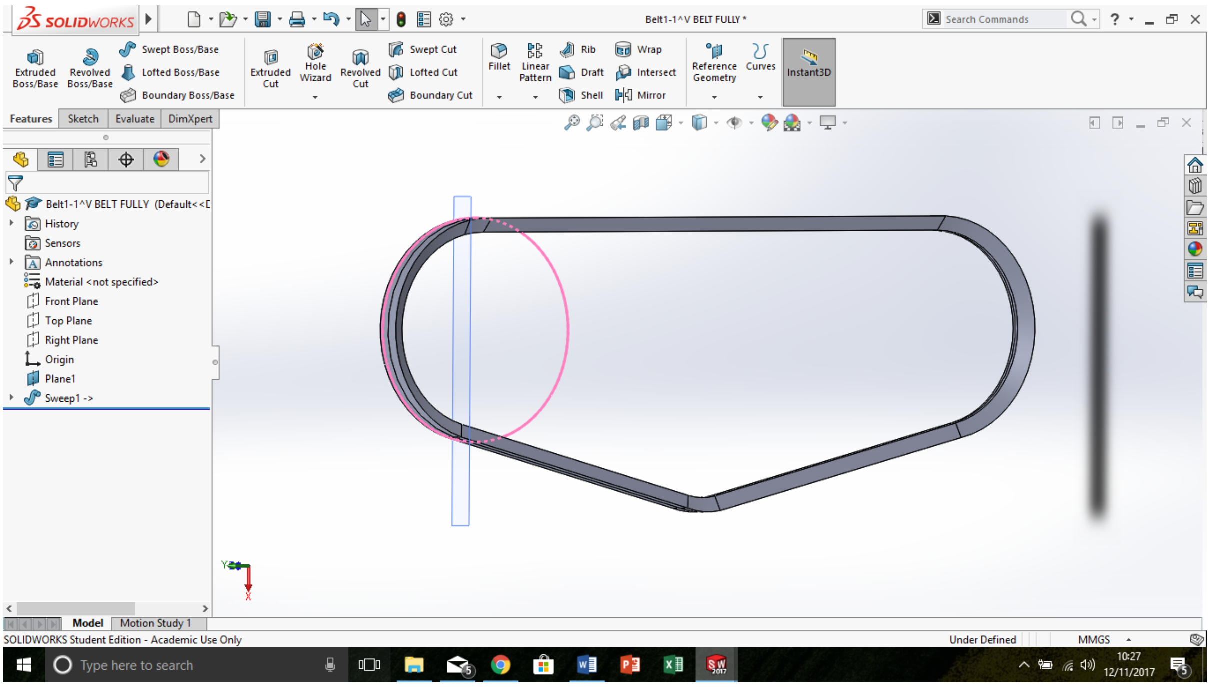


Figure 49 Assembly Step 14a

Note V belt does not touch base of pulley, gap = 1mm, hence blue line.

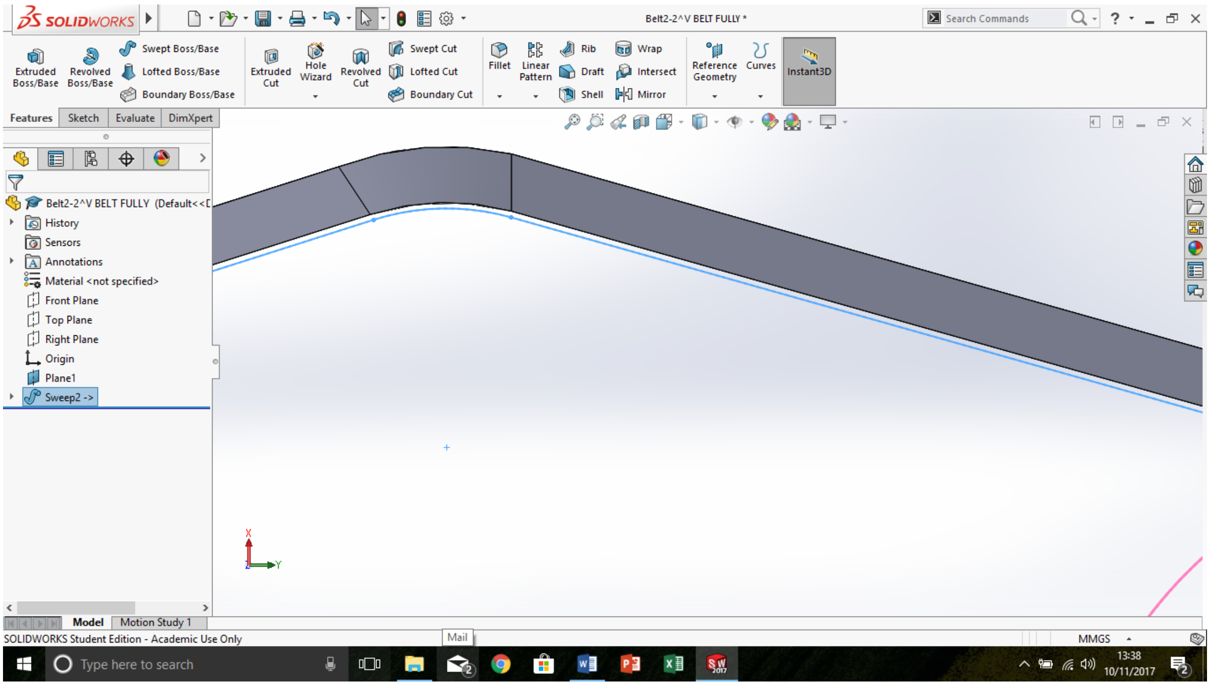


Figure 50 Assembly Step 14b

Step 15

Save at this point, and revert to the main design, now showing the belt made, and in position.

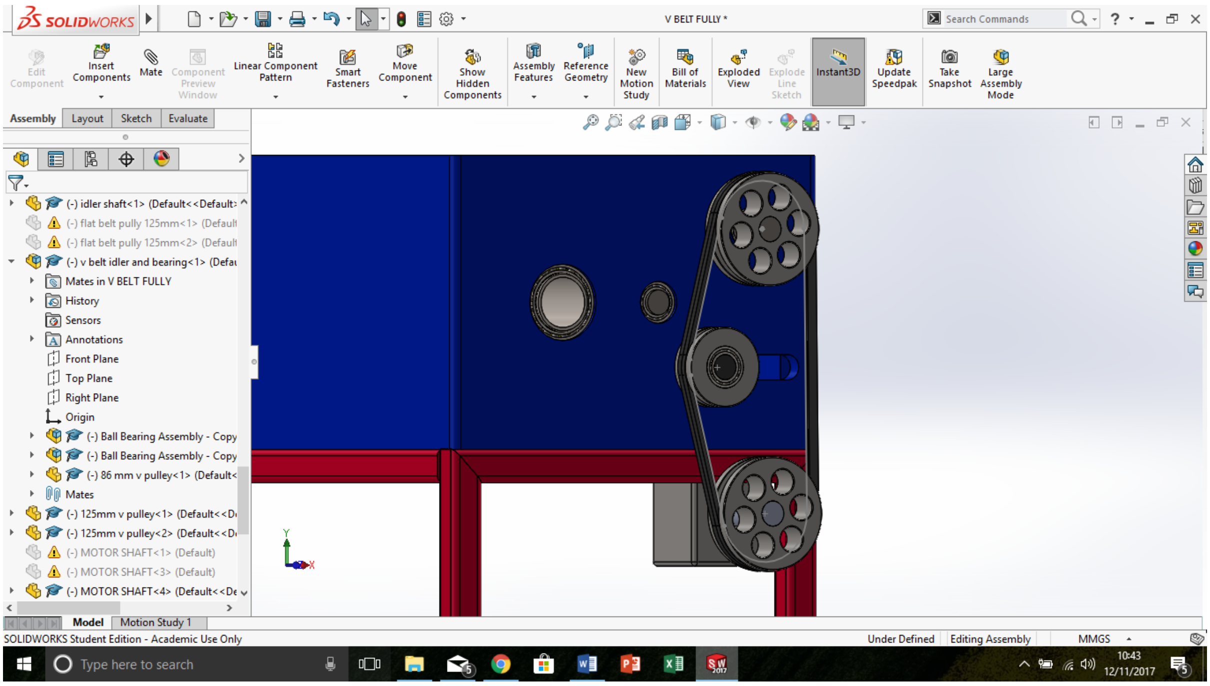


Figure 51 Assembly Step 15

Step 16

Add the spring-loaded tensioner, in this picture below, the belt length is 1050mm, 10mm bigger than the size brought, the reason being is that over time a belt will stretch, so the tensioner is spring loaded to keep the required pressure on the belt.

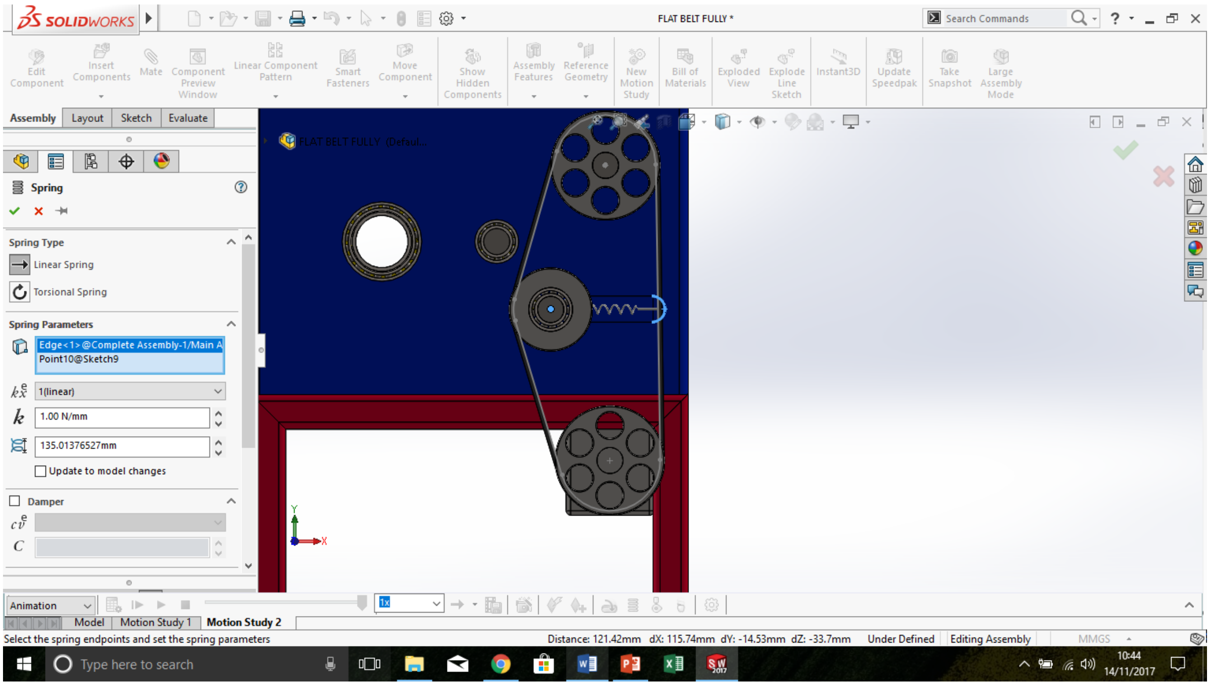


Figure 52 Assembly Step 16

Finite Element Analysis

Drive Shaft

The drive shaft has a rotational force applied of 358N, we need to select a material to suit the forces, I will apply 400N of force over the Ductile Iron I selected earlier. Below is a step by step guide of how to complete Finite Element Analysis (FEA).

Optimize

We need can optimise the material of the shaft if it either over performs or under performs, this method reduces cost and makes the component efficient in use. We may need to optimise, or we may not, this depends on the outcome of FEA. The next section after FEA will determine. Mr prediction would be that it will need optimization.

In short Optimization means to alter a component, and for a variety of reasons, in this case cost and weight are both factors. By changing a material to another or by restructuring the designed component.

Step 1

Select drive shaft and then select simulation express.

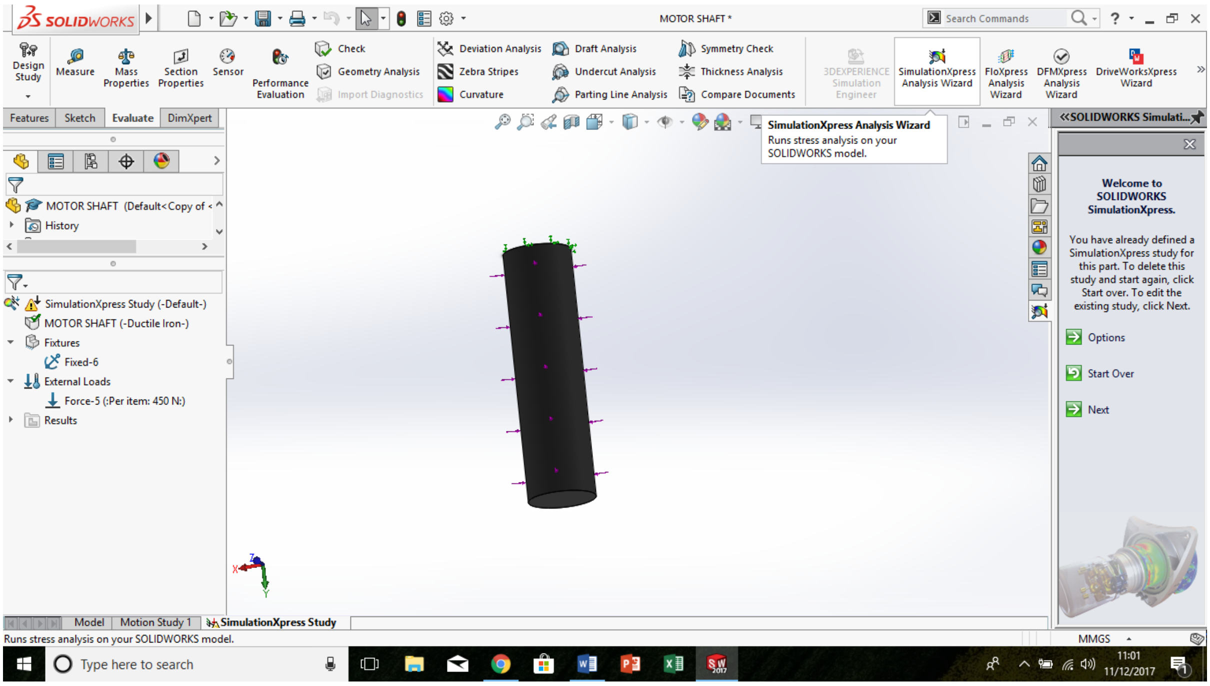


Figure 53 FEA Step 1

Step 2

Add fixture, for example the drive shaft will be connected to the motor, so it is fixed, this feature allows for an imaginary fixture.

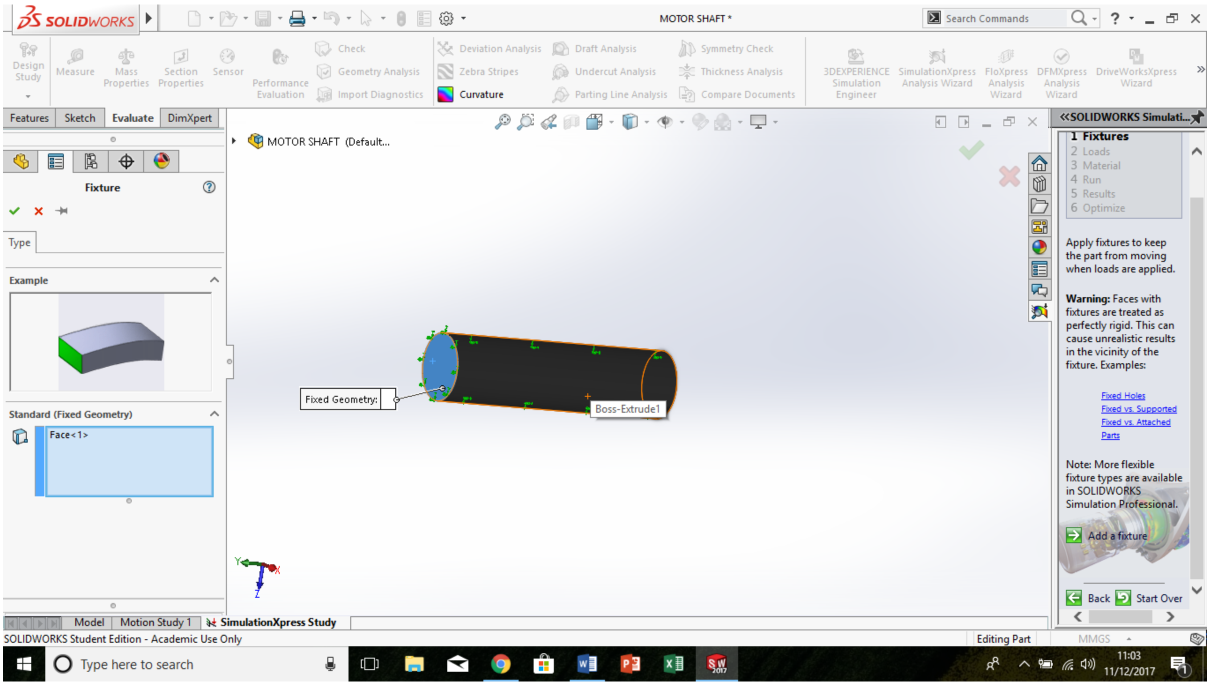


Figure 54 FEA Step 2

Step 3

Apply force or whichever property suits you, for me its rotary force acting on the Drive Shaft and given a have calculated a net force of 358N for the Drive shaft I will select a force of 400N to begin.

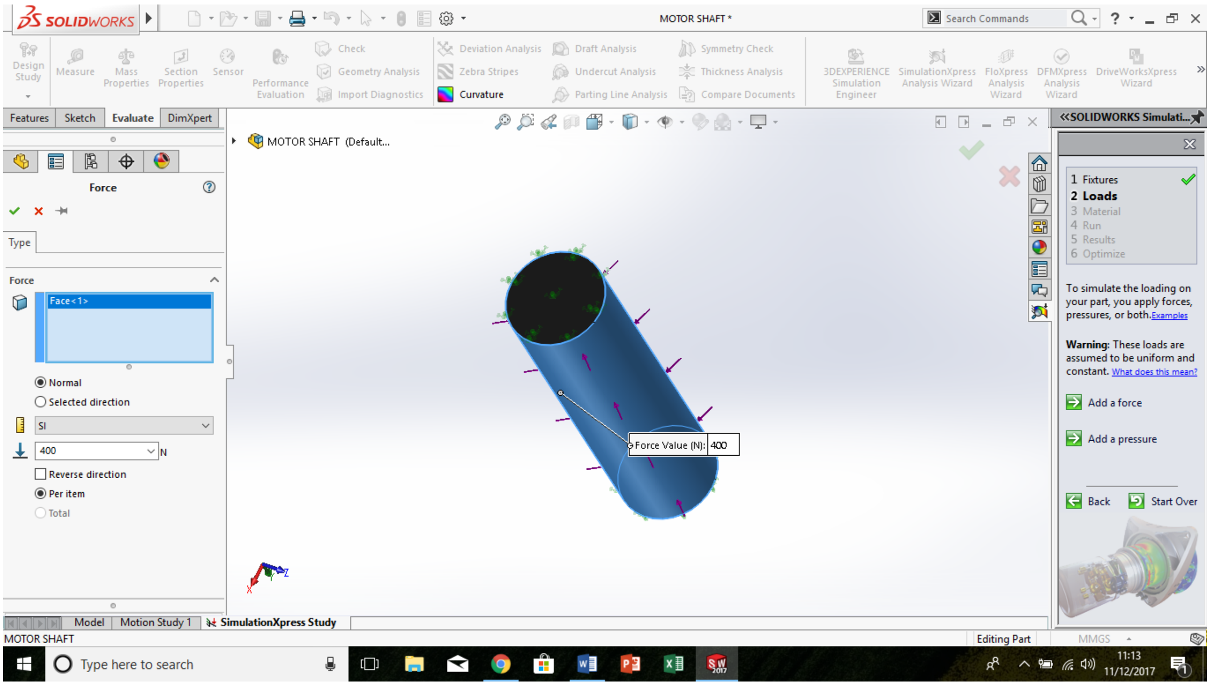


Figure 55 FEA Step 3

Step 4

Select material, I already selected the material I want so know need for change yet.

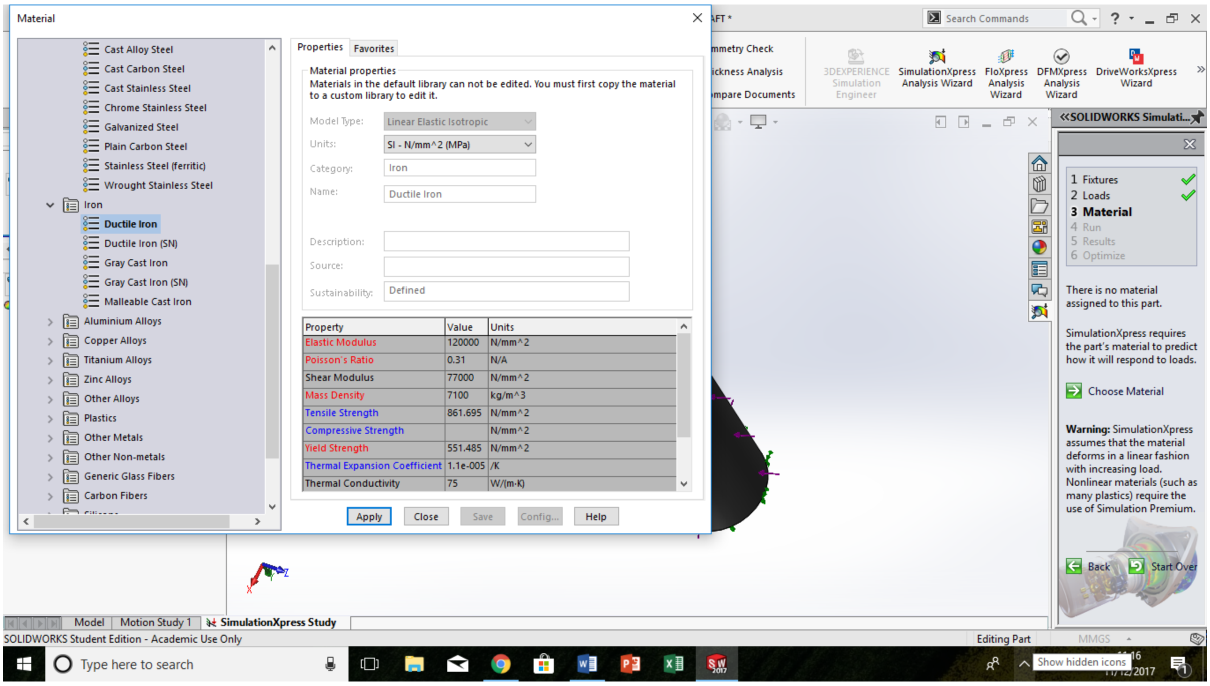


Figure 56 FEA Step 4

Step 5

Run simulation.

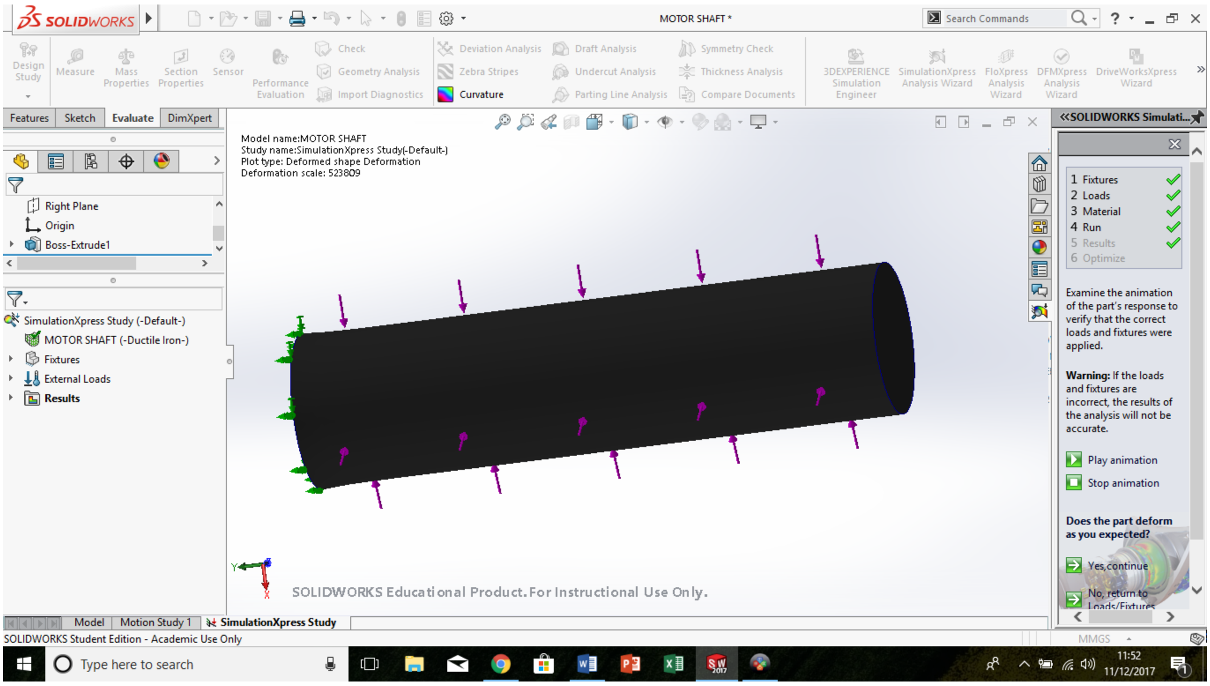


Figure 57 FEA Step 5

Step 6

Saftey factor, I only need a saftey factor of 1.5, which means 1.5 x times the strenth it needs to be and this design has a saftey factor of 8125.83.

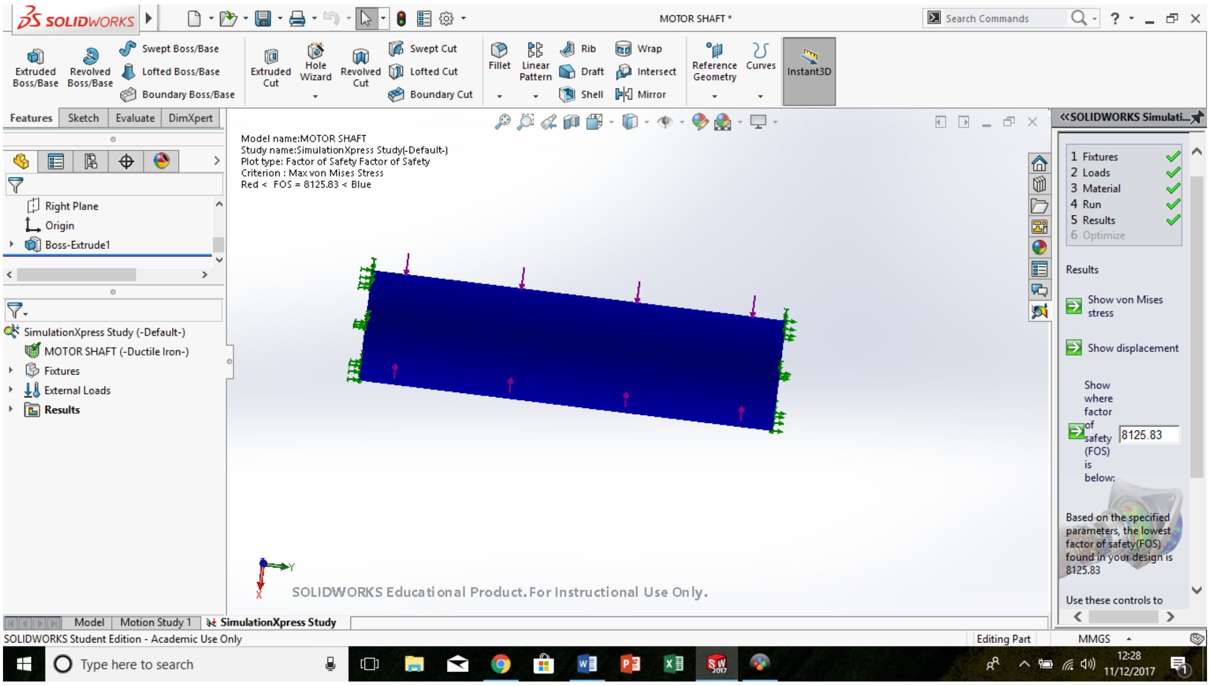


Figure 58 FEA Step 6

Step 7

Shows Von Mises Stress.

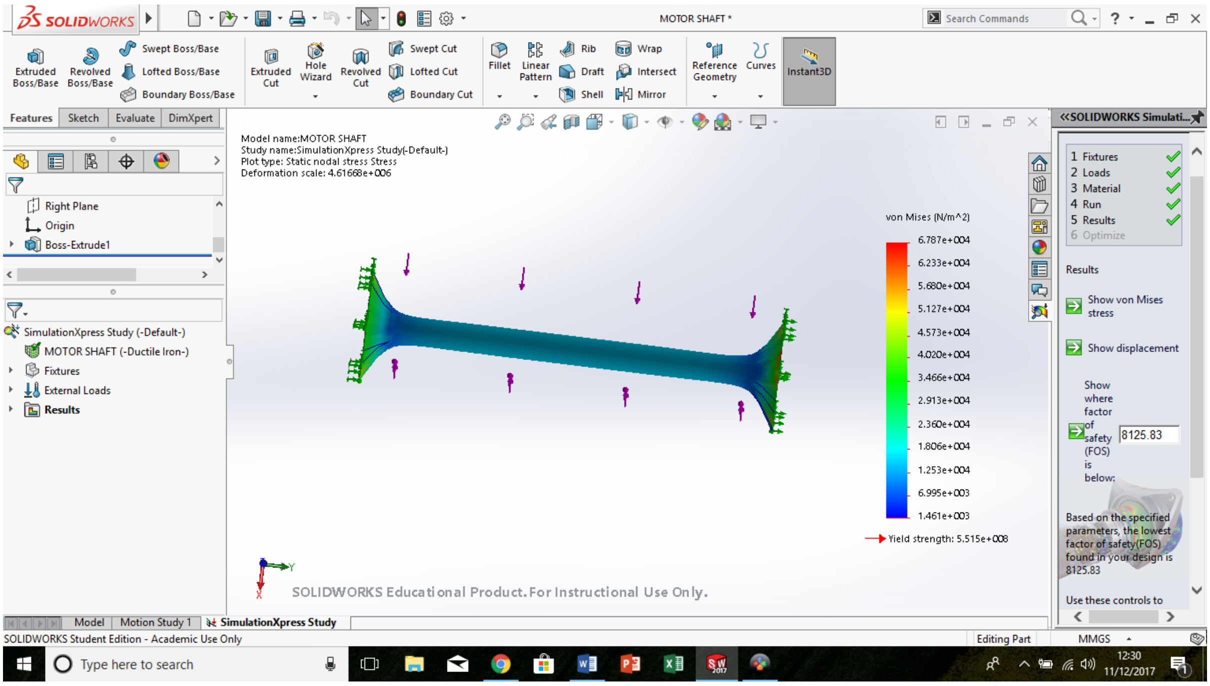


Figure 59 FEA Step 7

Step 8

Shows discplacement after force is applied.

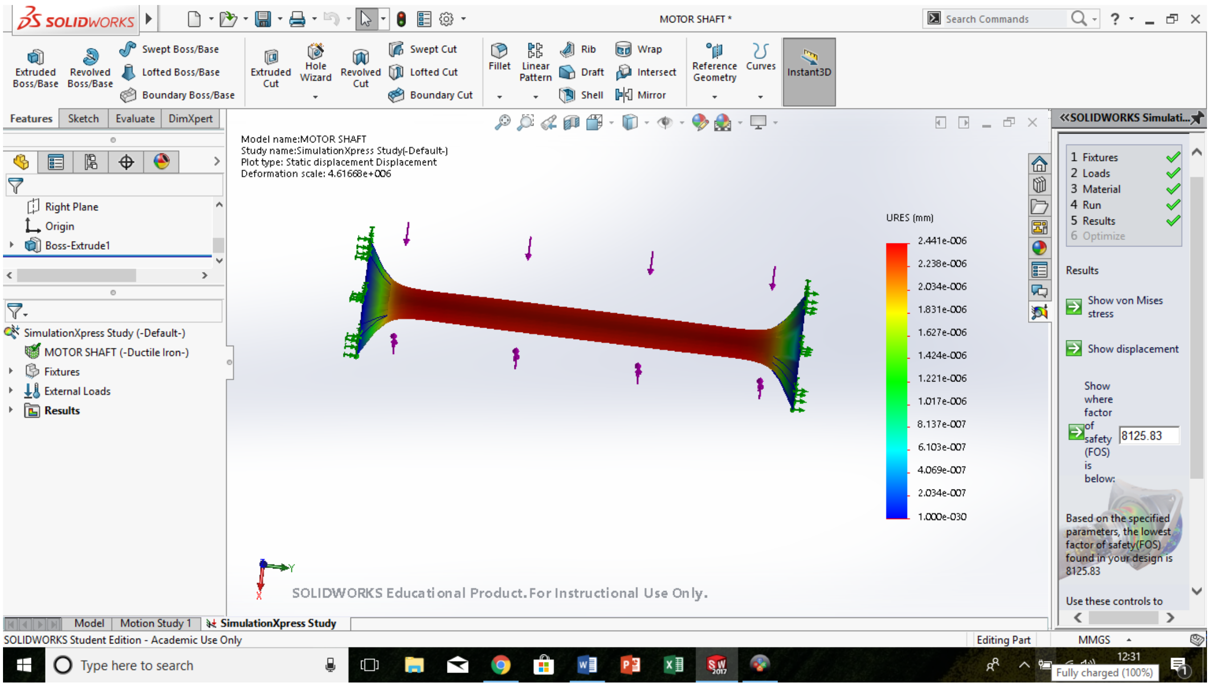


Figure 60 FEA Step 8

Conclusion

Ductile iron is over sufficient in terms of strength needed, so if we optimise the drive shaft, change the materials and alter a couple of features it will not affect the overall design, but could reduce cost.

SolidWorks is limited in FEA ability student edition. I would have liked to have done better here.

Optimisation

The Motor shafts material was ductile iron, we know that we must achieve over 358N, Ideally Aiming a bit higher at 400N, we will try to choose a material with a lower Factor of Safety, this is called optimisation where we improve a components feature.

Step 1

Select Drive Shaft in FEA mode, Simulation Express.

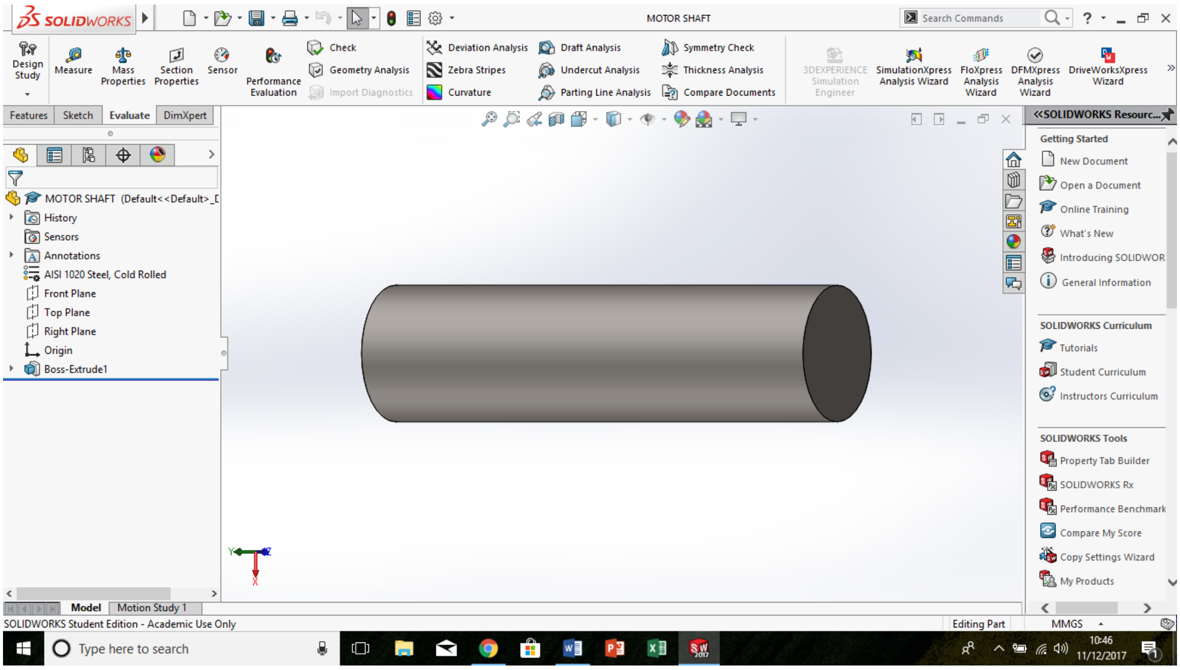


Figure 61 Optimisation Step 1

Step 2

Change material, Cold Drawn steel, tensile strength 385N, cheaper than Ductile Iron. This does not affect design.

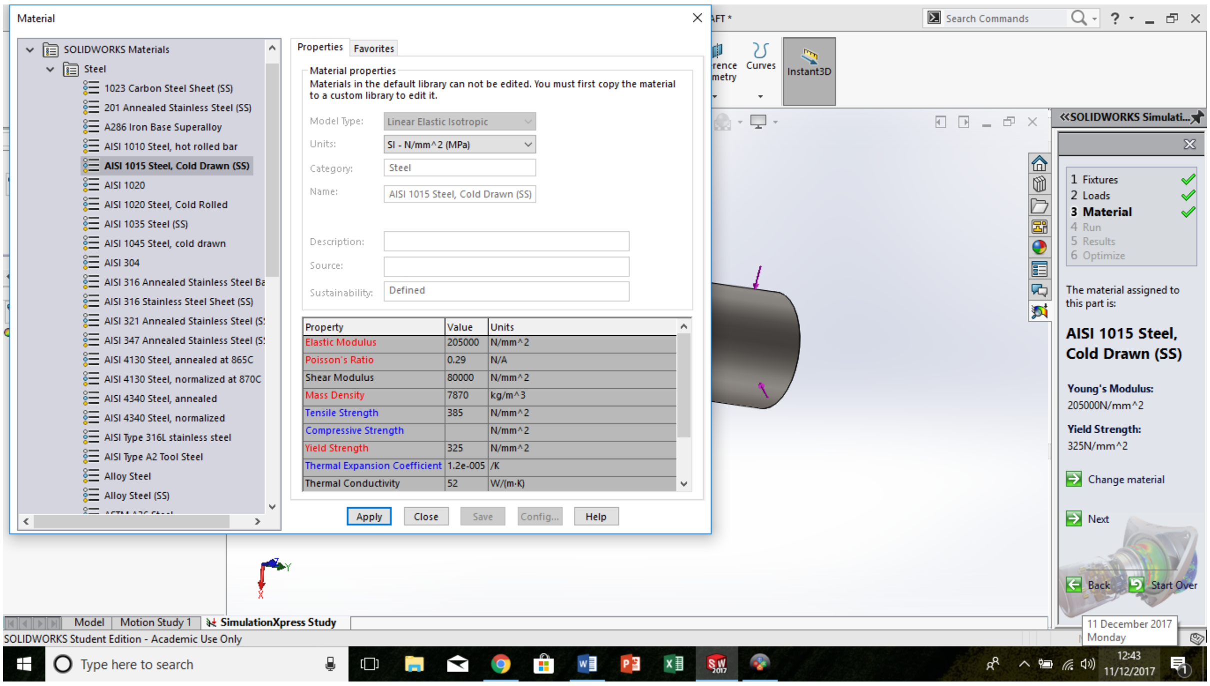


Figure 62 Optimisation Step 2

Step 3

Safety factor 3938, over half the amount of 8125.83 previoulsy factored. For torsion calculation I used a saftey factor of 5. Fact is the material is so strong because of its design.

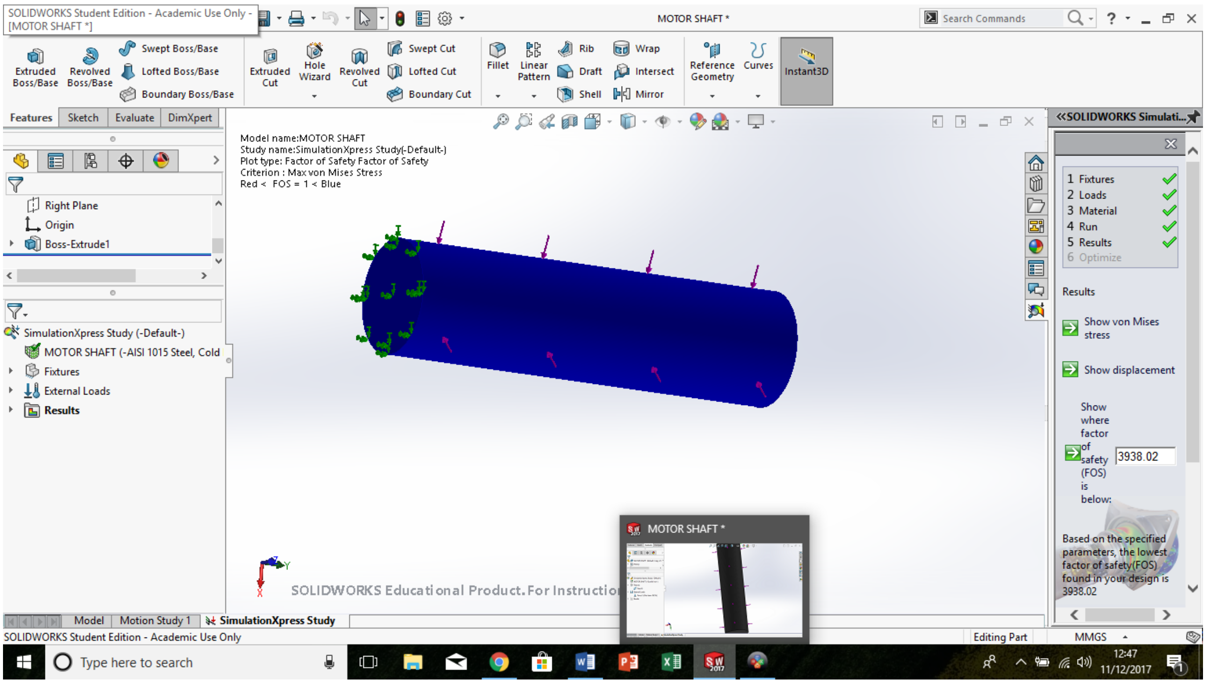


Figure 63 Optimisation Step 3

Step 4

Von Mise stress of new part.

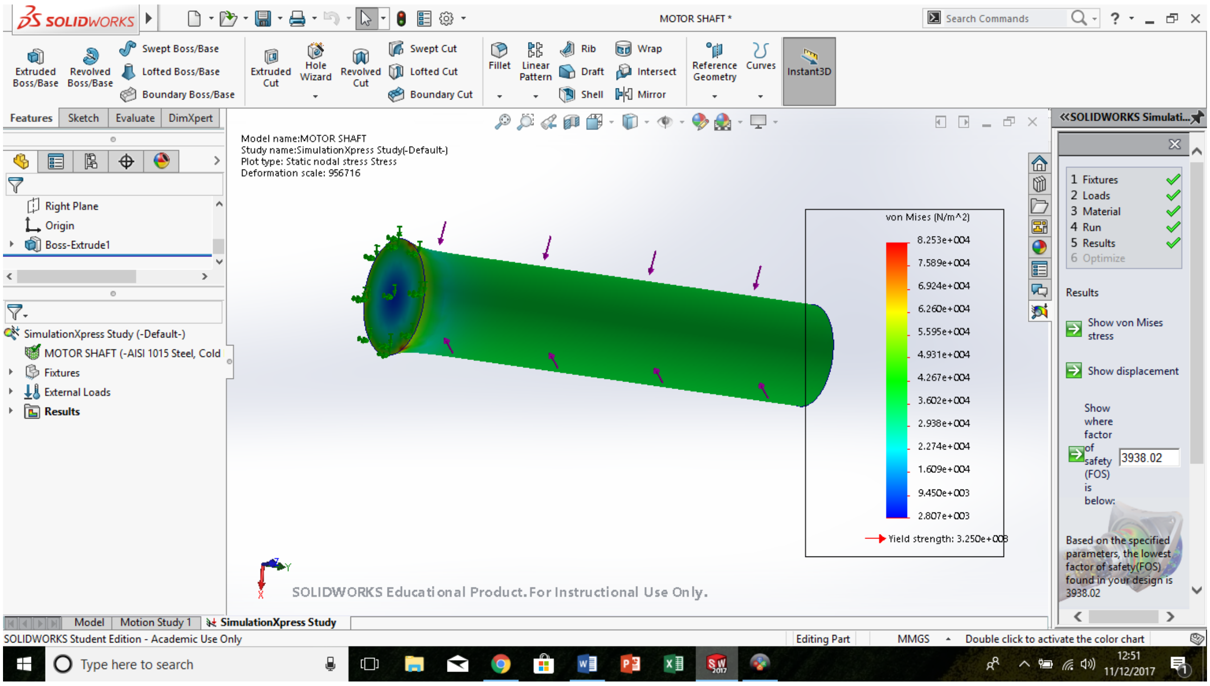


Figure 64 Optimisation Step 4

Step 5

Shows displacement.

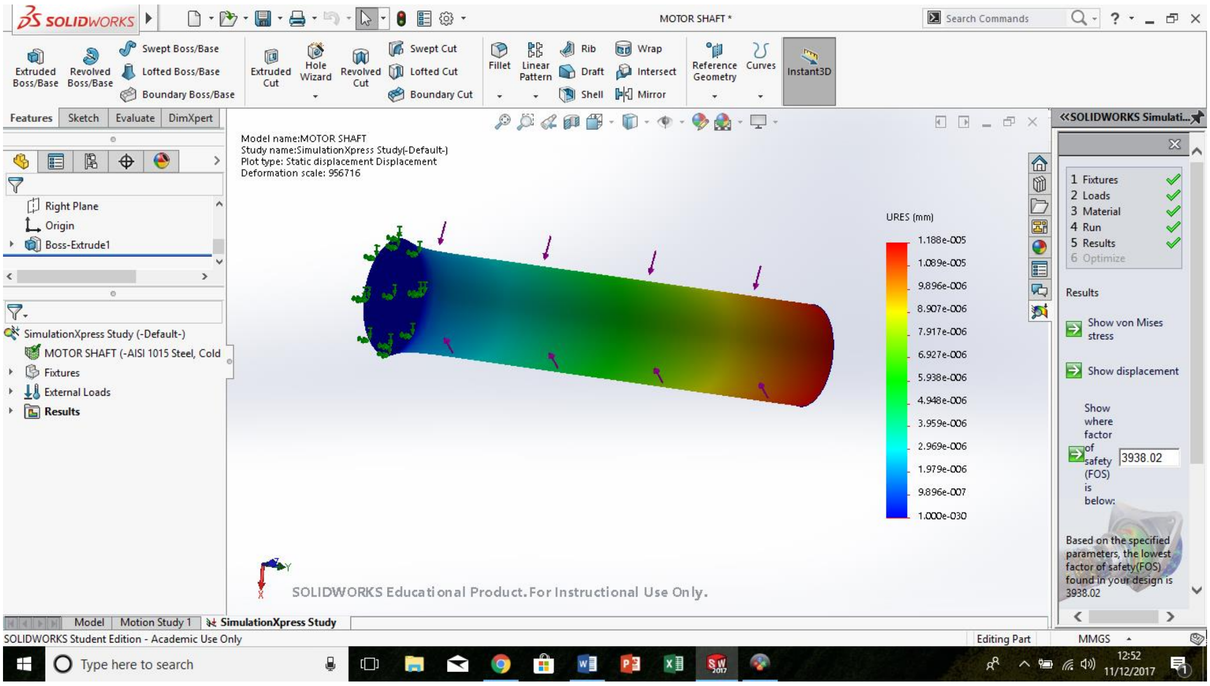
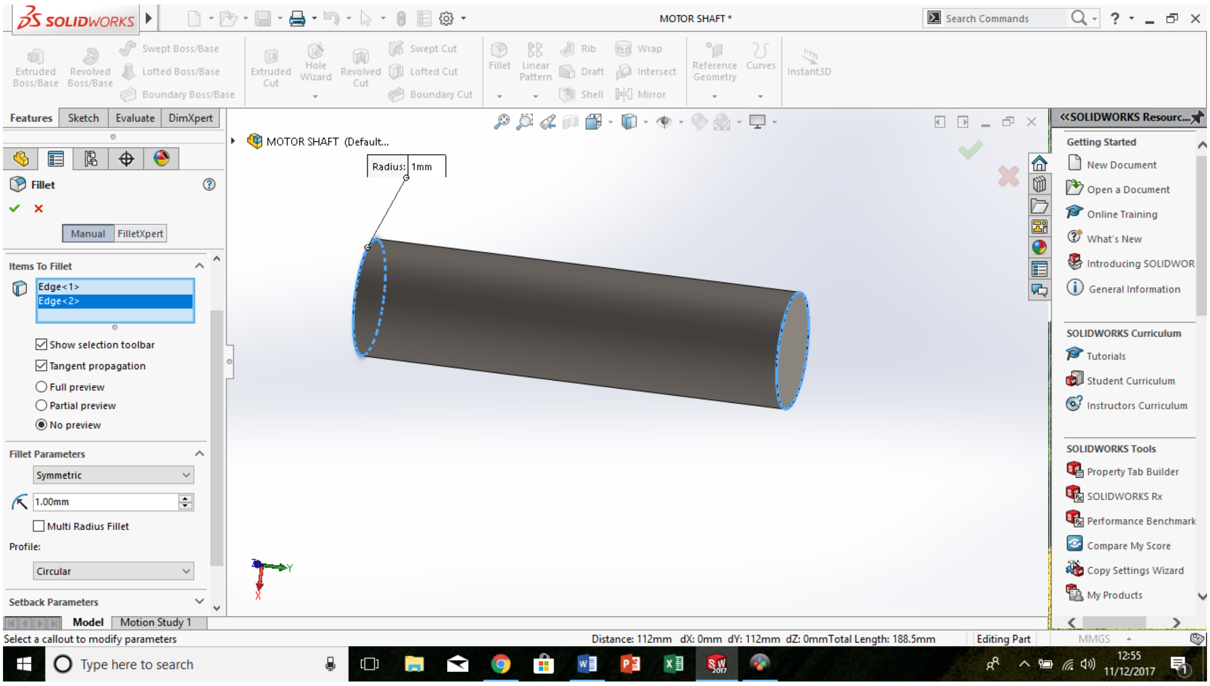


Figure 65 Optimisation Step 5

Step 6

Reduce excess material on drive shaft, will use fillet or chamfer, helps to connect drive shaft to pulley. gets rid of sharp edges, a method I always use, save the file and Optimization on this part is complete without altering design.



Finished Drive Shaft

Figure 66 Optimisation Step 6a

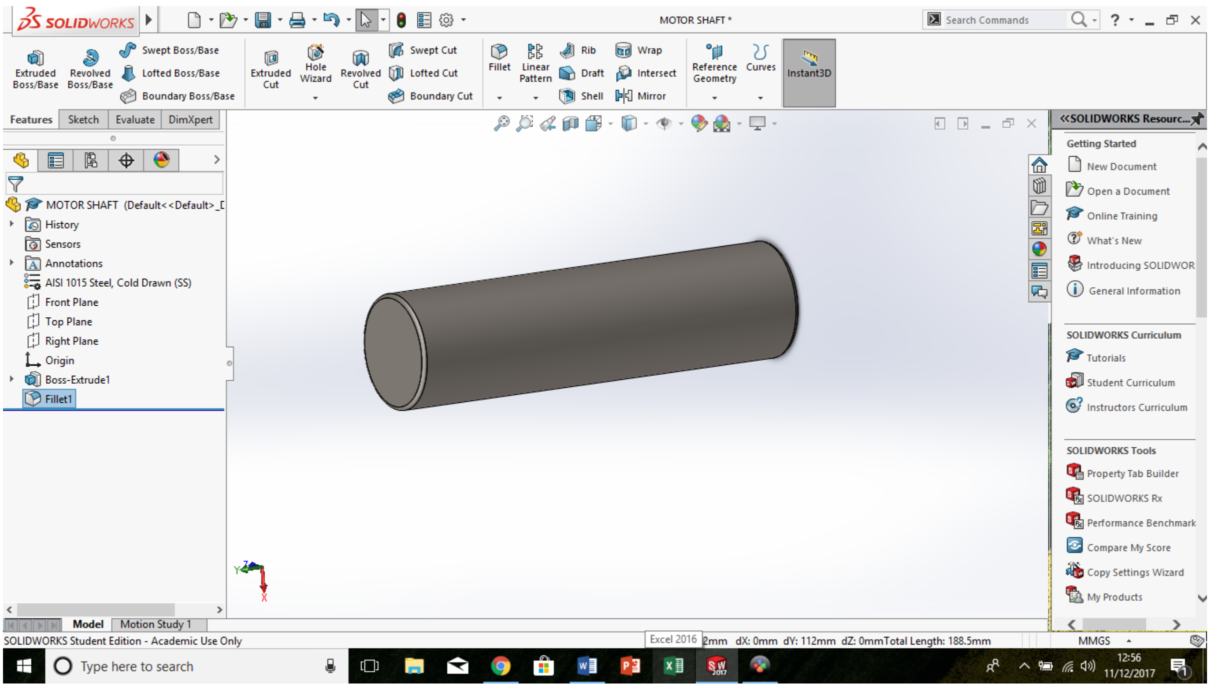


Figure 67 Optimisation Step 6b

Critical Conclusion

This report compares two types of Belt, the belts have the same contact surface area, having a design that helps incorporate both ideas for compatibility was my main target, belt speed, Length, Pitch of pulley and idlers and RPM's are the same for both systems. The difference is the belts, transmission power, torque, tension and weight, these factors suggest if a belt is capable to do the work required. And which belt if any would be better suited to the Lathe. Not before disregarding certain calculations as it turned out I needed an idler, so Effective Belt Length did not matter, nor did the angle of contact.

Once all data was utilised, a selection was made, the V belt, and the brake was added to the Lathe Design.

why

The Flat belt fails as it can't produce enough torque at 164N, to pull the weight of machine components worked out through mass and force, the work done required, is 358N.The V belt can produce enough torque required to pull the mass of 358N as it produces 604.9N. Note, the belt weight is 130 grams. Further analysis suggests belt thickness, weight and a low coefficient was the cause. The flat belt could be used but for a much lighter application as it weighs just 25 grams, otherwise the belt would snap. At 8.6m/s, a 1mm plie belt was chosen online, but with limited information, and looking at results after calculations I would need a Flat belt with at least 3 plies to produce enough torque, but they are expensive, so a V belt £3 from RS Components for this application is perfect.

Research, References and Standards

Standards

V Belt

API 1B, RMA IP 20, DIN 2215, ISO 4184 and BS3790

Flat Belt

JIS B 1852

ISO 22

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Appendix

Arc of Contact

The results found are detailed in the table below.

Readings were taken at 50N.

Flat leather belt at 15° intervals.

Table 29 Arc of Contact Flat Belt

Buffer/degrees	Value	change
30°	45	5
45°	42	8
60°	40	10
75°	36	14
90°	35	15
105°	31	10
120°	29	21
135°	26	24
150°	25	25
165°	22	28
180°	21	29

From the results, we can see that for the flat belt, for maximum power to be transmitted, it must have a minimum 180° angle of contact before power can be transmitted efficiently before slip.

Rubber V-belt.

Determined by experiment the minimum contact angle of a V belt drive to transmit maximum power.

Readings were taken at 15° intervals.

Table 30 Arc of Contact V Belt

Buffer/degrees	Value	change
30°	29	21
45°	20	30
60°	15	35
75°	8	42
90°	6	44
105°	5	45

120°	7	Starts to slip at this point, too much tension along the ark

HND at Loughborough College (Chris Rooney)

Arc of contact correction factor Cβ Arc of contact small pulley [º] Correction factor 230 1,11

Table 31 Arc of Contact Factor

Angle of Contact Factor°	Correction Factor
220	109
210	107
200	105
190	102
180	100
170	0.97
160	0.94
150	0.91
140	0.88
130	0.84
120	0.80
110	0.76
100	0.72
91	0.67
83	0.63