Appendix F: Strength calculations

	Maximum Torque [Nm]	Experienced Torque [Nm]	Maximum tangential force [N]	Experienced tangential force [N]	Experienced radial force [N]	Rotational speed [rad/s]
Gear 1 [12T]	3	0.941	450	148.228	53.95	14.537
Gear 2 [36T]	3.4	2.627	700	137.879	50.184	4.508
Gear 3 [24T]	3	2.627	300	206.819	75.276	4.508
Gear 4 [24T]	3	2.489	300	195.99	71.335	4.272
Gear 5 [12T]	3	2.489	450	391.98	142.669	4.272
Gear 6 [36T]	3.4	6.946	700	364	132.709	1.324
Gear 7 [24T]	1	6.946	580	546.923	199.064	1.324
Gear 8 [48T]	1.2	13.269	580	522.417	190.144	0.638
Gear 9 [48T]	1.2	12.922	580	508.74	185.166	0.621

Figure 1: Summary of calculations from Appendix C

In the summary calculations from figure 1, it can be seen that Gear 6, 7, 8 and 9 need to be reinforced because the torque they experience is greater that the torque it can withstand.

Gear 6

Gear 6 is 36 teeth spur gear.

Gear 6 yield strength: $S_{y\_gear6} := 66\ MPa$

Gear 6 maximum torque: $T_{max\_gear6} := 3.4\ N \cdot m$

Gear 6 boss thickness: $t_{boss\_gear6} := 9.5\ mm$

The k-factor for gear 6 can be calculated using the above properties.

Gear 6 k-factor: $$k_{gear6} := \frac{T_{max\_gear6}}{t_{boss\_gear6} \cdot S_{y\_gear6}}$$

$$k_{gear6} = 5.423\ mm^2$$

Now the thickness of the sheet metal plate can be determined. Sheet metal is made with hot rolled mild plate

The sheet metal plate yield strength: $$S_{y\_plate1} := 250\ MPa$$

Torque experienced by the plate: $$T_{plate1} := 6.946\ N \cdot m$$

Plate thickness needed by the plate: $$t_{plate1} := \frac{T_{plate1}}{k_{gear6} \cdot S_{y\_plate1}}$$

$$t_{plate1} = 0.712\ mm$$

Gear 7

Gear 7 is 24 teeth spur gear.

Gear 7 yield strength: $$S_{y\_gear7} := 66\ MPa$$

Gear 7 maximum torque: $$T_{max\_gear7} := 1\ N \cdot m$$

Gear 7 boss thickness: $$t_{boss\_gear7} := 9.5\ mm$$

The k-factor for gear 7 can be calculated using the above properties.

Gear 7 k-factor:

$$k_{gear7} := \frac{T_{max\_gear7}}{t_{boss\_gear7} \cdot S_{y\_gear7}}$$

$$k_{gear7} = 1.595\ mm^2$$

Now the thickness of the sheet metal plate can be determined. Sheet metal is made with hot rolled mild plate

The sheet metal plate yield strength:

$$S_{y\_plate7} := 250\ MPa$$

Torque experienced by the plate:

$$T_{plate7} := 6.946\ N \cdot m$$

Plate thickness needed by the plate:

$$t_{plate7} := \frac{T_{plate7}}{k_{gear7} \cdot S_{y\_plate7}}$$

$$t_{plate7} = 0.958\ mm$$

Gear 8

Gear 8 is 48 teeth spur gear.

Gear 8 yield strength:

$$S_{y\_gear8} := 66\ MPa$$

Gear 8 maximum torque:

$$T_{max\_gear8} := 1\ N \cdot m$$

Gear 8 boss thickness:

$$t_{boss\_gear8} := 9.5\ mm$$

The k-factor for gear 8 can be calculated using the above properties.

Gear 8 k-factor:

$$k_{gear8} := \frac{T_{max\_gear8}}{t_{boss\_gear8} \cdot S_{y\_gear8}}$$

$$k_{gear8} = 1.595 \; mm^2$$

Now the thickness of the sheet metal plate can be determined. Sheet metal is made with hot rolled mild plate

The sheet metal plate yield strength:

$$S_{y\_plate8} := 250 \; MPa$$

Torque experienced by the plate:

$$T_{plate8} := 13.269 \; N \cdot m$$

Plate thickness needed by the plate:

$$t_{plate8} := \frac{T_{plate8}}{k_{gear8} \cdot S_{y\_plate8}}$$

$$t_{plate8} = 1.659 \; mm$$

Gear 9

Gear 9 is 48 teeth spur gear.

Gear 9 yield strength:

$$S_{y\_gear9} := 66 \; MPa$$

Gear 9 maximum torque:

$$T_{max\_gear9} := 1 \; N \cdot m$$

Gear 8 boss thickness: $t_{boss\_gear9} := 9.5\ mm$

The k-factor for gear 8 can be calculated using the above properties.

Gear 8 k-factor:

$$k_{gear9} := \frac{T_{max\_gear9}}{t_{boss\_gear9} \cdot S_{y\_gear9}}$$

$$k_{gear9} = 1.595\ mm^2$$

Now the thickness of the sheet metal plate can be determined. Sheet metal is made with hot rolled mild plate

The sheet metal plate yield strength: $S_{y\_plate9} := 250\ MPa$

Torque experienced by the plate: $T_{plate9} := 12.922\ N \cdot m$

Plate thickness needed by the plate:

$$t_{plate9} := \frac{T_{plate9}}{k_{gear9} \cdot S_{y\_plate9}}$$

$$t_{plate9} = 1.615\ mm$$

	Maximum torque [Nm]	Experienced torque [Nm]	Plate thickness needed [mm]
Gear 6 [36T]	3.4	6.946	
Gear 7 [24T]	1	6.946	
Gear 8 [48T]	1.2	13.269	
Gear 9 [48T]	1.2	12.922	

Figure 2: Summary table of plate thickness need

The above table shows how much thickness is needed for the plates to reinforce the gears that need to be supported.

Base

The base of the pipe bending platform has a lot of parts on it. Thus, it will experience forces due to the weight of the parts. The forces can be converted to stresses.

Big roller

Big roller mass: $$M_{big\_roller} := \frac{22.72}{1000} \cdot kg$$

Big roller force: $$F_{big\_roller} := M_{big\_roller} \cdot \left(9.81\ \frac{m}{s^2}\right)$$

$$F_{big\_roller} = 0.223\ N$$

Big roller outer radius: $$OD_{big\_roller} := \frac{35}{2}\ mm$$

Big roller inner radius: $$ID_{big\_roller} := \frac{8}{2}\ mm$$

Big roller area: $A_{big\_roller} := \pi \cdot \left(OD_{big\_roller}^{\ 2} - ID_{big\_roller}^{\ 2}\right)$

Big roller stress: $\sigma_{big\_roller} := \dfrac{F_{big\_roller}}{A_{big\_roller}}$

$\sigma_{big\_roller} = 244.43\ Pa$

Pipe support

Pipe support mass: $M_{pipe\_s} := \dfrac{1.26}{1000} \cdot kg$

Pipe support force: $F_{pipe\_s} := M_{pipe\_s} \cdot \left(9.81\ \dfrac{m}{s^2}\right)$

$F_{pipe\_s} = 0.012\ N$

Pipe support area: $A_{pipe\_s} := 26 \cdot 21\ mm^2$

Pipe support stress: $\sigma_{pipe\_s} := \dfrac{F_{pipe\_s}}{A_{pipe\_s}}$

$\sigma_{pipe\_s} = 22.638\ Pa$

Lower & upper microswitch holder and microswitch

Lower & upper microswitch holder and microswitch mass [lum]: $M_{lum} := \dfrac{19.1}{1000} \cdot kg$

Lower & upper microswitch holder and microswitch force [lum]: $F_{lum} := M_{lum} \cdot \left(9.81\ \dfrac{m}{s^2}\right)$

$F_{lum} = 0.187\ N$

Lower & upper microswitch holder and microswitch area [lum]:

$$A_{lum} := 26 \cdot 7 \; mm^2$$

Lower & upper microswitch holder and microswitch stress [lum]:

$$\sigma_{lum} := \frac{F_{lum}}{A_{lum}}$$

$$\sigma_{lum} = \left(1.03 \cdot 10^3\right) \; Pa$$

<u>Total stress on the base</u>

Total stress on the base:

$$\sigma_{base\_ex} := \sigma_{lum} + \sigma_{pipe\_s} + \sigma_{big\_roller}$$

$$\sigma_{base\_ex} = 0.001 \; MPa$$

The base tensile strength at yield:

$$\sigma_{base\_yield} := 220 \; MPa$$

Factor of safety:

$$FOC_{base} := \frac{\sigma_{base\_yield}}{\sigma_{base\_ex}}$$

$$FOC_{base} = 1.697 \cdot 10^5$$

Lower casing

The base of the lower housing has a lot components, it will be 3D printed using PLA plastic. Thus, it needs to be ensured that it will not fail due bending.

Total mass of the parts acting on the lower housing:

$$M_{lower\_s} := \frac{560}{1000} \cdot kg$$

Total mass of the parts acting on the lower housing:

$$F_{lower\_s} := M_{lower\_s} \cdot \left(9.81 \frac{m}{s^2}\right)$$

$$F_{lower\_s} = 5.494\ N$$

Total mass of the parts acting on the lower housing:

$$A_{lower\_s} := 44899.54\ mm^2$$

Total mass of the parts acting on the lower housing:

$$\sigma_{lower\_s} := \frac{F_{lower\_s}}{A_{lower\_s}}$$

$$\sigma_{lower\_s} = 122.353\ Pa$$

The stress experienced by the lower housing is very small compared to the lower housing flexural strength. Thus, the lower housing will be able to withstand bending forces applied perpendicular to its longitudinal axis.

Flexural strength of the lower housing:

$$\sigma_{flexural\_lower\_s} := 80\ MPa$$

Factor of safety:

$$FOC_{lower\_s} := \frac{\sigma_{flexural\_lower\_s}}{\sigma_{lower\_s}}$$

$$FOC_{lower\_s} = 6.538 \cdot 10^5$$

Bending die

Bending die is responsible for bending the pipe and it will be in contact with the pipe. Thus, the strength of the bending die needs to be determined.

The bending die will be machined using low carbon steel

Bending die tensile strength: $\sigma_{tensile\_die} := 550\ MPa$

Bending die yield strength: $\sigma_{yield\_die} := 250\ MPa$

The tensile stress experienced by the die can be determined. By first determining the force the will be experienced by the die.

The calculate bending moment of the die: $M_{die} := 12.922\ N \cdot m$

The distance that the force is acting: $D_{die} := 10\ mm$

The area that the force is acting: $A_{die} := 75.4\ mm^2$

The force acting on the die:

$$F_{die} := \frac{M_{die}}{D_{die}}$$

$$F_{die} = \left(1.292 \cdot 10^3\right)\ N$$

The tensile stress acting on the die:

$$\sigma_{die\_ex} := \frac{F_{die}}{A_{die}}$$

$$\sigma_{die\_ex} = 17.138\ MPa$$

Factor of safety:

$$FOC_{die} := \frac{\sigma_{tensile\_die}}{\sigma_{die\_ex}}$$

$$FOC_{die} = 32.093$$

Handle

The handle of the design will be responsible for allowing the user to lift the design, it will be 3D printed using PLA plastic. Thus, it needs to be ensured that it will not .

Total mass of the parts acting on the handle:

$$M_{handle} := 1.11 \cdot kg$$

Total mass of the parts acting on the handle:

$$F_{handle} := M_{handle} \cdot \left(9.81\ \frac{m}{s^2}\right)$$

$$F_{handle} = 10.889\ N$$

Total mass of the parts acting on the handle:

$$A_{handle} := 44899.54\ mm^2$$

Total mass of the parts acting on the handle:

$$\sigma_{handle\_ex} := \frac{F_{handle}}{A_{handle}}$$

$$\sigma_{handle\_ex} = 242.521\ Pa$$

The stress experienced by the lower housing is very small compared to the lower housing flexural strength. Thus, the lower housing will be able to withstand bending forces applied perpendicular to its longitudinal axis.

Flexural strength of the lower housing:

$$\sigma_{flexural\_handle} := 80\ MPa$$

Factor of safety:

$$FOC_{handle} := \frac{\sigma_{flexural\_handle}}{\sigma_{handle\_ex}}$$

$$FOC_{handle} = 3.299 \cdot 10^{5}$$