Appendix A: Bending requirements

The user requirements document gives the properties of the pipe that must be bent by the battery operated bending tool. Those properties are:

Pipe yield strength: $T_{yield} := 650 \cdot MPa$

Pipe thickness: $t := 1.5\ mm$

Pipe outer diameter: $OD := 6\ mm$

Using the pipe outer diameter and thickness, the inner diameter can be calculated.

Pipe inner diameter: $ID := OD - 2 \cdot t$

$ID = 3\ mm$

Using the above pipe properties, the required bending moment to bend the pipe can be calculated.

To determine the maximum stress due to bending the **flexure formula** is used:

$$\sigma_{max} = \frac{M \times c}{I_x} = \frac{M}{Z_x}$$

where:

- σ_{max} is the maximum stress at the farthest surface from the neutral axis (it can be top or bottom)
- M is the bending moment along the length of the beam where the stress is calculated
  - if the maximum bending stress is required then M is the maximum bending moment acting on the beam
- I_x is the moment of inertia about x (horizontal) centroidal axis
- c is the maximum distance from the centroidal axis to the extreme fiber (again, this can be to the top or bottom of the shape)
- Z_x is called **section modulus** and is a term that combines the moment of inertia and the distance to the extreme fiber ($Z_x = I_x / c$)

Figure 1: Bending stress formula

The above formula is taken from a book called "Mechanic of Materials" 11th edition, written by Russell C. Hibbeler

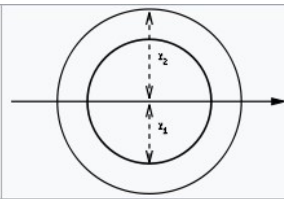
Circular hollow section		$S = \frac{\pi\left(r_2^4 - r_1^4\right)}{4r_2} = \frac{\pi(d_2^4 - d_1^4)}{32d_2}$	Solid arrow represents neutral axis

Figure 1: Section modulus formula

The above formula is taken from a book called "Mechanic of Materials" 11th edition, written by Russell C. Hibbeler.

Section Modulus:

$$SM := \frac{\pi \cdot \left(OD^4 - ID^4\right)}{32 \cdot OD}$$

$$SM = 19.88\ mm^3$$

Bending moment required:

$$M_{required} := SM \cdot T_{yield}$$

$$M_{required} = 12.922\ N \cdot m$$

Now that the required bending moment is calculated, the gearbox should be designed such that the torque of the last gears is greater or equal to the required bending moment.