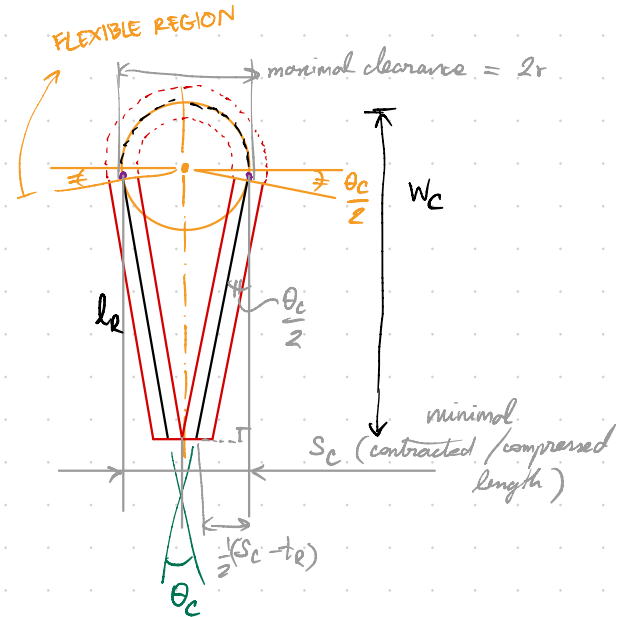
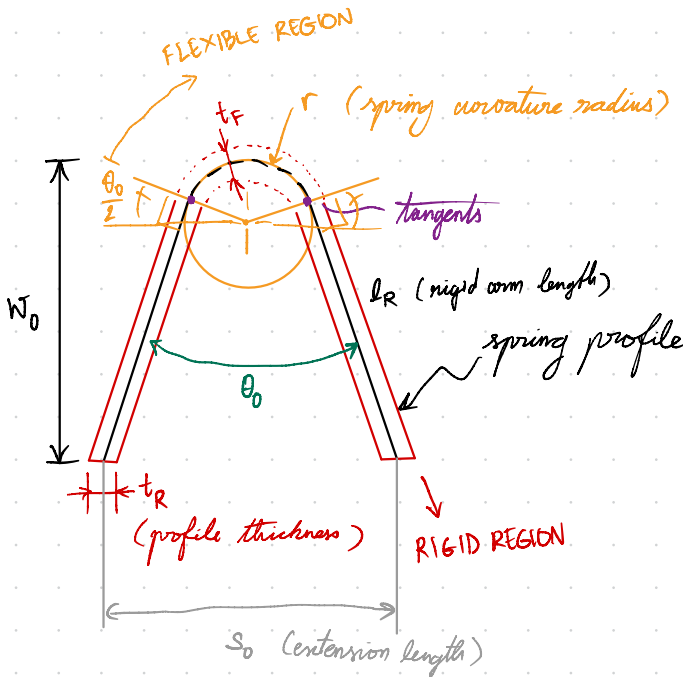
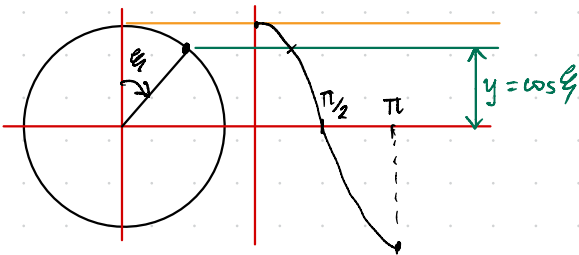


I. The Anatomy



$$S_0 = 2l_R \sin \frac{\theta_0}{2} + (\text{flexible width}) \quad (1)$$

Consider a unit circle and $f(\alpha) = \cos(\alpha)$:



$$\text{Therefore, flex width} = 2r \cos \frac{\theta_0}{2} \quad (2)$$

$$\rightarrow S_0 = 2l_R \sin \frac{\theta_0}{2} + 2r \cos \frac{\theta_0}{2} \quad (3)$$

Simplify via $a \sin x + b \cos x \rightarrow A \sin(x + \phi)$;
 $A = \sqrt{a^2 + b^2}$, $\phi = \arctan \frac{b}{a}$

$$\therefore S_0 = 2\sqrt{l_R^2 + r^2} \sin\left(\frac{\theta_0}{2} + \arctan \frac{r}{l_R}\right) \quad (4)$$

For W_x , it's just trig. co-function. ($\Delta\psi = \frac{\pi}{2}$)

$$\text{As such, } W_0 = l_R \cos \frac{\theta_0}{2} + r \sin \frac{\theta_0}{2} \quad (5)$$

$$\therefore W_0 = \sqrt{l_R^2 + r^2} \sin\left(\frac{\theta_0}{2} + \operatorname{arccot} \frac{r}{l_R}\right) \quad (6)$$

To find minimal length, use (2):

$$S_c = 2r \cos \frac{\theta_c}{2} \quad (7)$$

(@ $t_R = 0$)

You can, then, use S_0 and S_c to calculate retraction ratio and diff.

Also, S_c can be solved using: (@ $t_R \neq 0$)

$$\sin \frac{\theta_c}{2} = \frac{S_c - t_R}{2l_R} \quad (8)$$

(5), (6):

$$S_c = \frac{r^2 t_R - \sqrt{4l_R^4 r^2 + 4l_R^2 r^4 - l_R^2 r^2 t_R^2}}{l_R^2 + r^2} \quad (9)$$

$$\text{and } \theta_c = 2 \arctan \frac{r}{l_R} - 2 \arcsin \frac{t_R/2}{\sqrt{l_R^2 + r^2}} \quad (10)$$

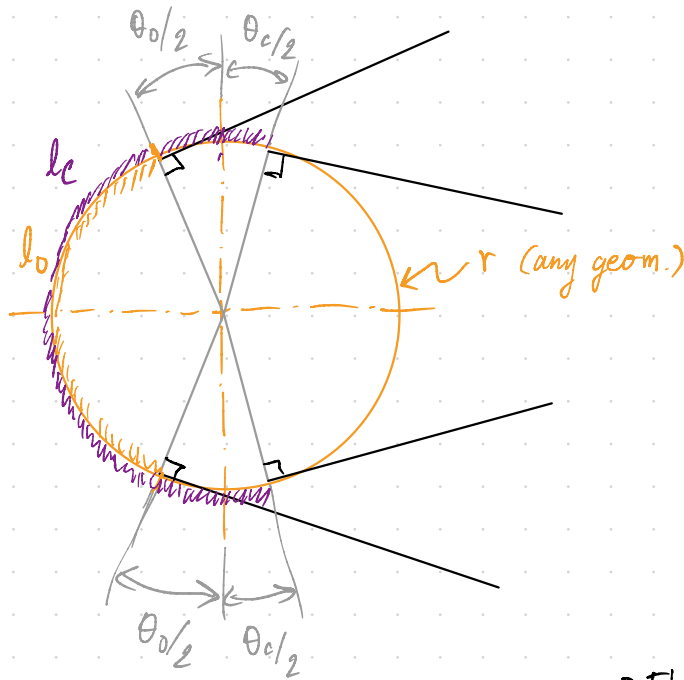
t_R can be approximated to 0 for simpler form.

$$W_c = r(1 + \sin \frac{\theta_c}{2}) + l_R \cos \frac{\theta_c}{2} \quad (11)$$

using (9), (10)

$\rightarrow$ If $|W_0 - W_c|$ is too much, the spring can "till" of its compression axis.

Material Elongation : Material CAN break, and can be elongated to some degree before it breaks. Many experiments are conducted to find 3DP ~ %elongation at break.



$\left\{ \begin{array}{l} l_0 : \text{initial material length} \\ l_c : \text{material length after compression of the spring} \end{array} \right.$

Both can be easily computed:

$$\begin{aligned} l_0 &= (\pi - \theta_0) r \\ \text{and } l_c &= (\pi + \theta_c) r \end{aligned} \quad (11)$$

→ Elongation

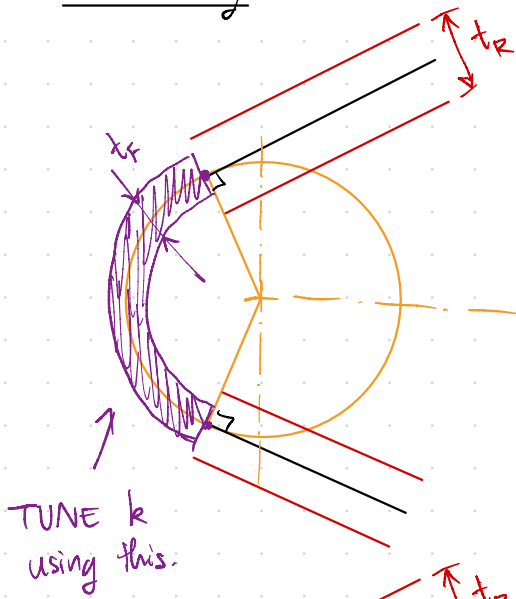
$$1 + \epsilon = \frac{\pi + \theta_c}{\pi - \theta_0} \quad (12)$$

For example TPU has $> 100\%$ elongation at break.
and PLA typically has $< 10\%$.

Note that real condition might differ from the calculation and material may even fail before its yield.

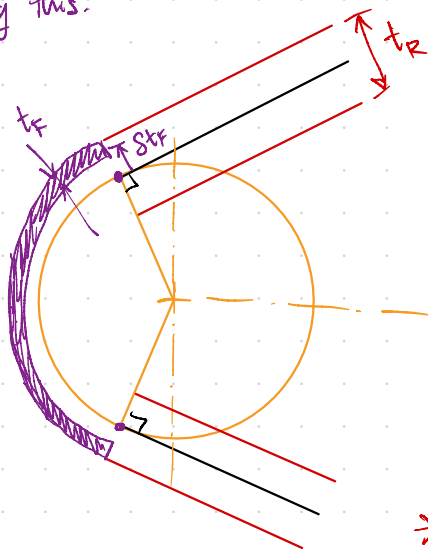
* Also, you must consider material's fatigue limit.
(N cycles before failure)

II. Printing



Adjust t_F to other values other than t_R
to change rigidity/flexibility of the spring.

(EXPERIMENTAL)



You can even offset t_F to be off the axis.



helps with stress relief

* Try using 100% infill with concentric pattern.
and tune k using t_F .