Spring Length Dependence on Angle of Rotation

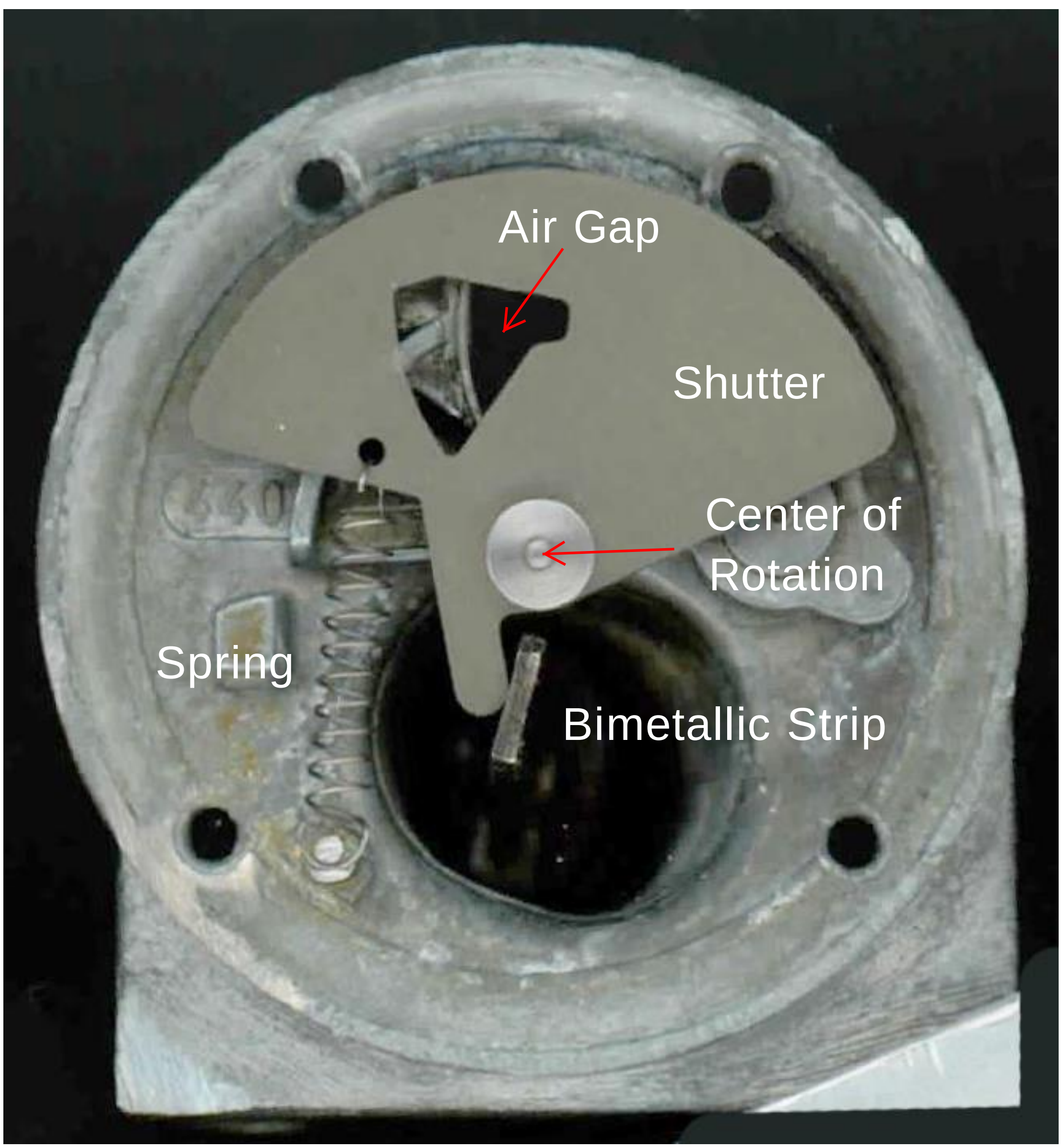
Open Auxiliary Air Valve and its components

Principle of Operation:

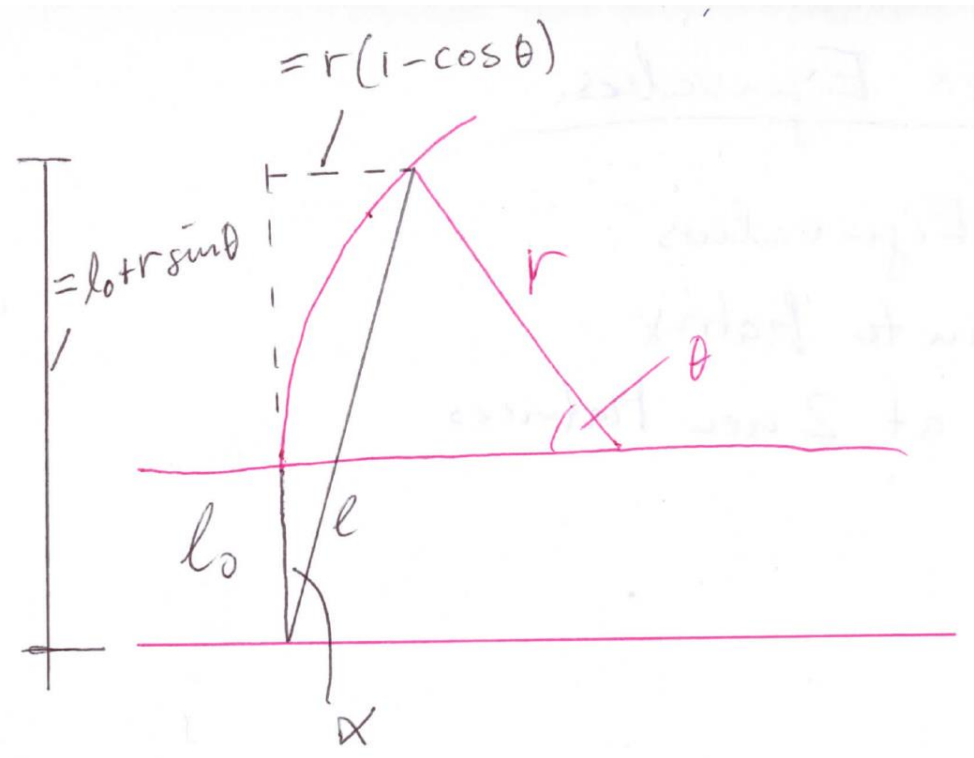
The spring wants to close the shutter by rotating it counter clockwise, the bimetallic strip resists that force.

When it gets heated (engine running) it moves to the right and allows the spring to close the shutter. When the engine cools down the bimetallic strip moves back to the left and forces the shutter back open.

The resulting air gap when the shutter is open determines the amount of additional idle air during cold-start and warm-up.



The attachment point of the spring moves on a circular arc when the shutter opens or closes. The length l_0 is for the closed shutter and l for the open shutter. Spring moves towards the center of rotation when the shutter opens.



$$r = 10.66mm, l_0 = 17.2mm, \theta_{open} = 46.8°$$

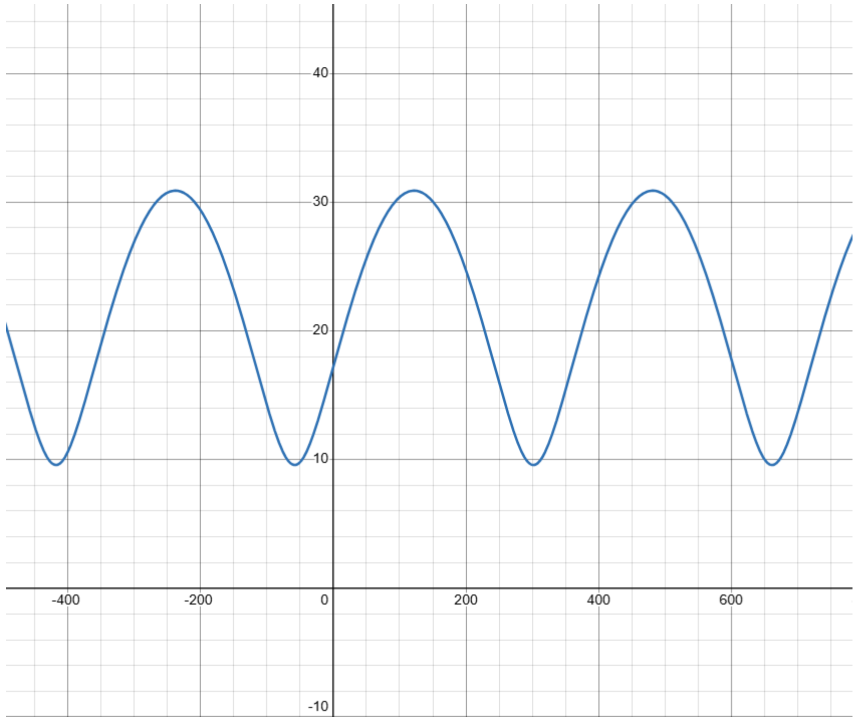
$$Using\ a^2 + b^2 = c^2\ and\ cos^2\theta + sin^2\theta = 1$$

$$r^2(1 - cos\theta)^2 + (l_0 + rsin\theta)^2 = l^2$$

$$l = \sqrt{2r^2(1 - cos\theta) + l_0(l_0 + 2rsin\theta)}$$

$$l_{meas.} = 25.00mm, \qquad l_{calc.} = 25.19mm$$

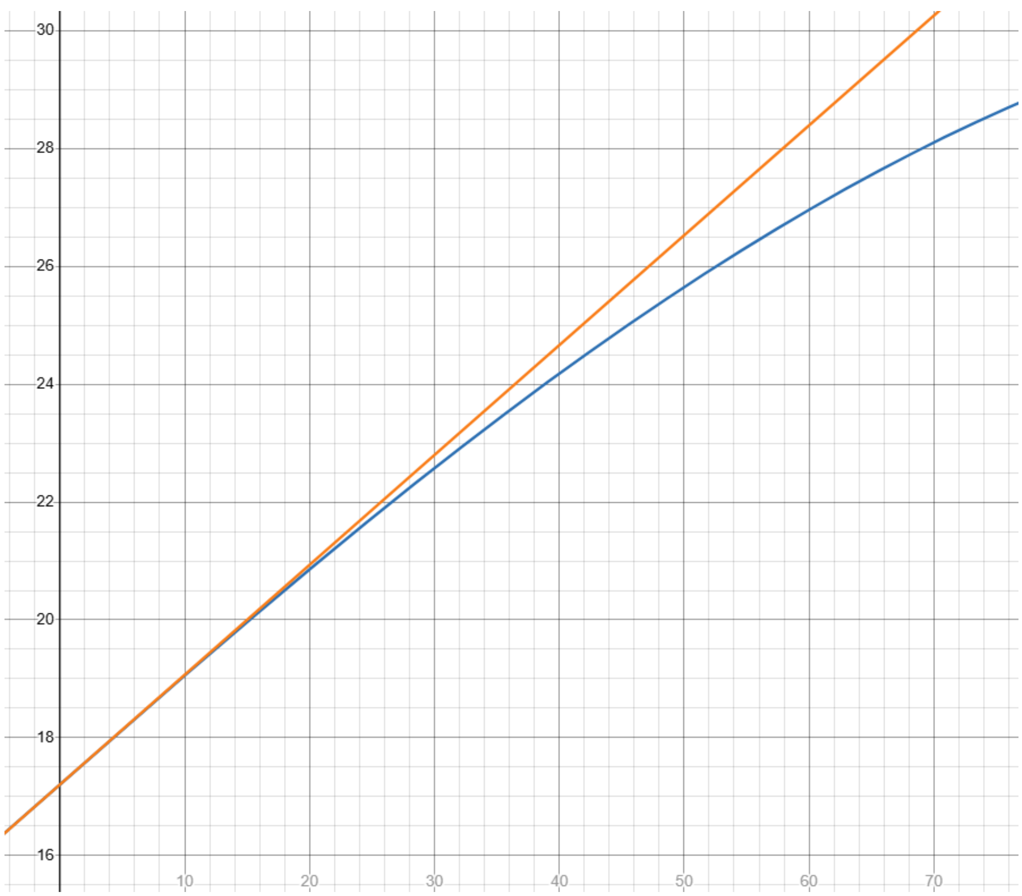
Resulting function:



Spring length in mm vs. Shutter angle in degrees from fully closed

Range of AAV angle = 0 - 46.8°

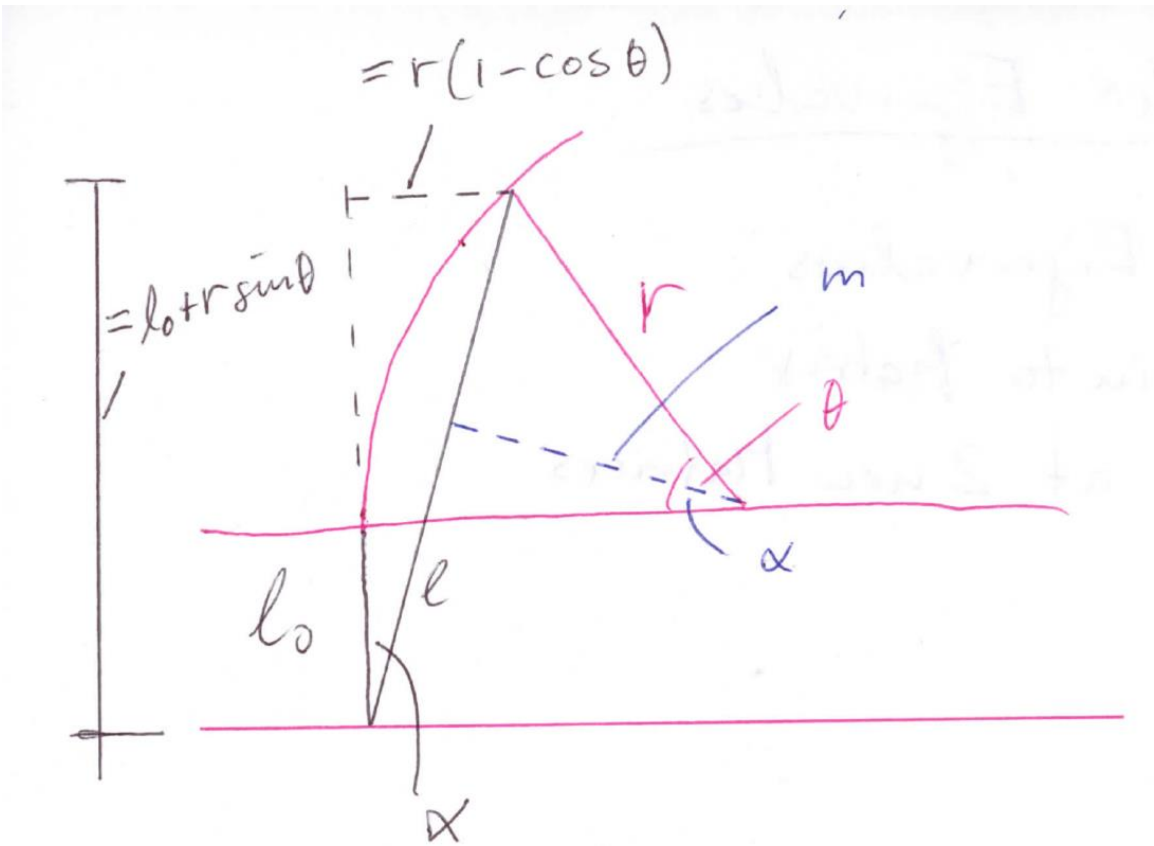
Deviation from linear relationship: ≈ 3% at 48°



Spring length in mm vs. Shutter angle in degrees from fully closed

Moment Arm Dependence on Rotational Angle

Since the spring moves towards the center of rotation when the shutter opens, the moment arm "m" gets shorter with increasing angle.



$$r = 10.66mm, l_0 = 17.2mm,\ \theta_{open} = 46.8°$$

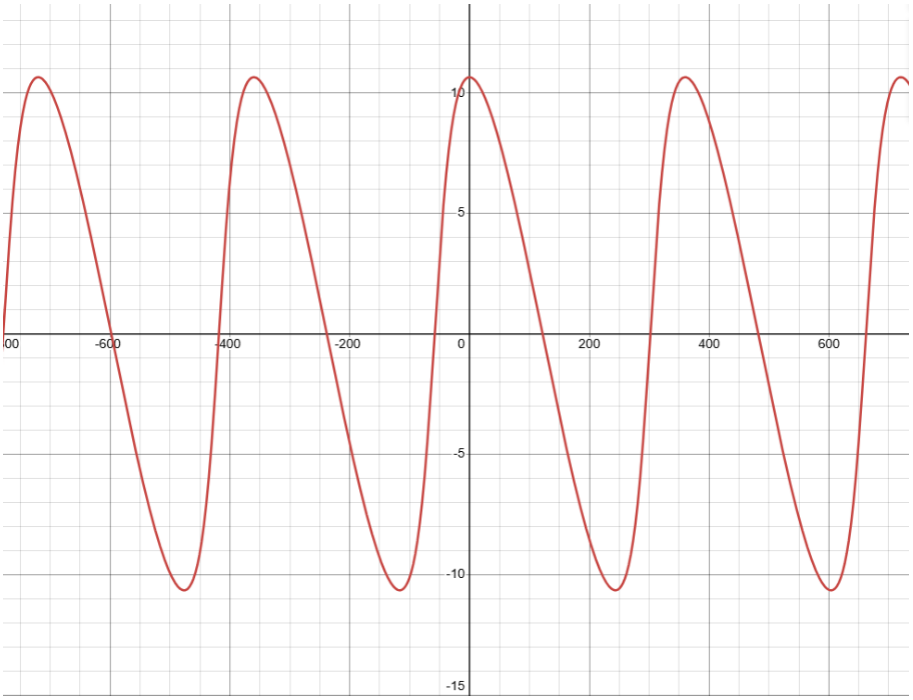
$$\tan(\alpha) = \frac{r(1-cos\theta)}{l_0+r\cdot sin\theta};\ \alpha = tan^{-1}(\frac{r(1-cos\theta)}{l_0+r\cdot sin\theta})$$

$$Moment\ arm\ \ m:$$

$$m = r\cdot\cos(\theta-\alpha) = r\cdot\cos\left(\theta - tan^{-1}\left(\frac{r(1-cos\theta)}{l_0+r\cdot sin\theta}\right)\right)$$

$$m_{meas.} = 8.30mm, \qquad m_{calc.} = 8.27mm$$

Resulting function:



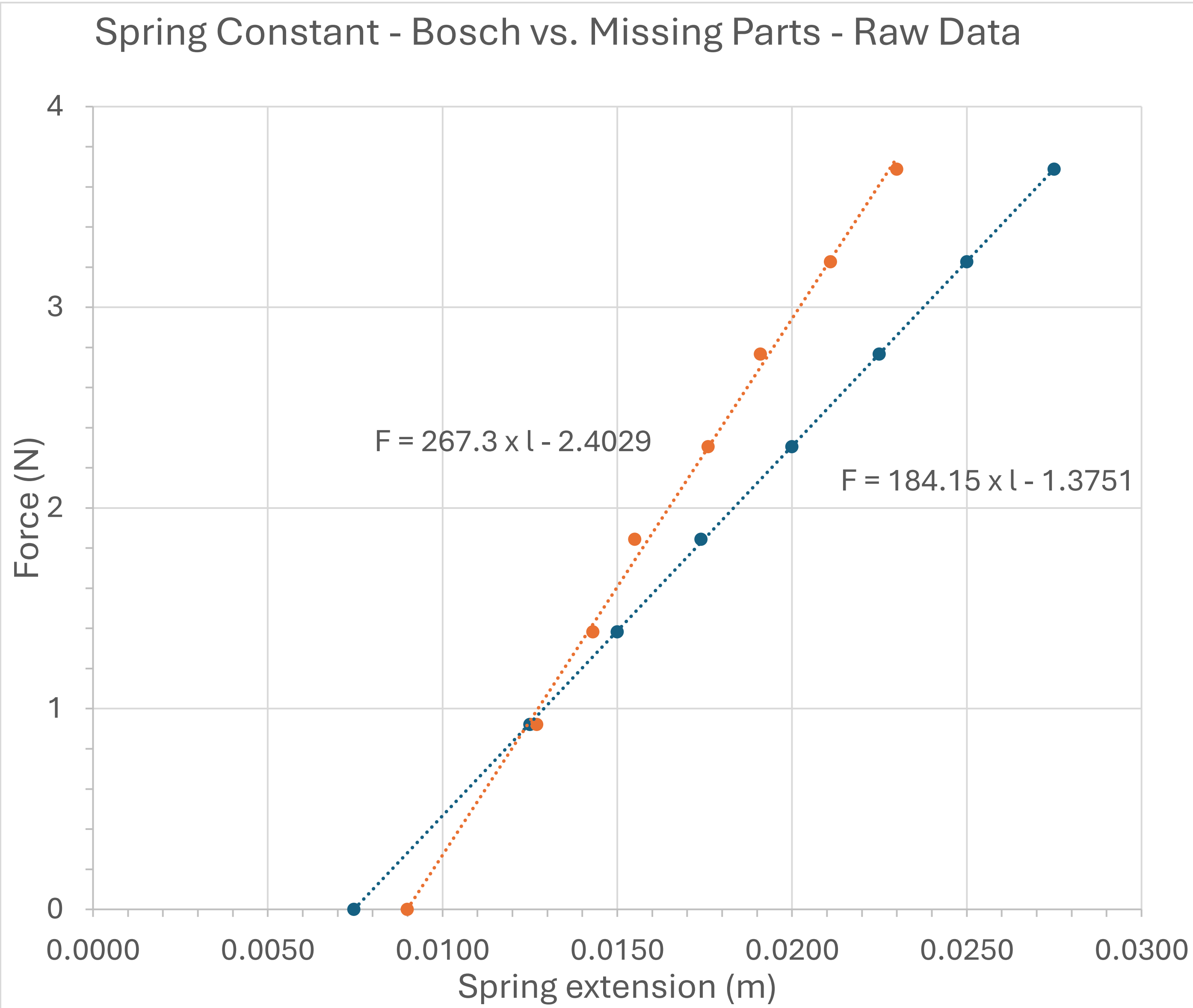
Moment arm in mm vs. Shutter angle in degrees from fully closed

Range of AAV angle = 0 - 140°

Moment arm in mm vs. Shutter angle in degrees from fully closed

Moment arm gets shorter as spring is extended

Spring Constant Measurements:



$$F = k \cdot l + c$$

$$Bosch: k = 2.6730, c = -2.4029$$

$$Miss. P: k = 184.15, c = -1.3751$$

$$F_{Spring} = k \cdot l + c$$

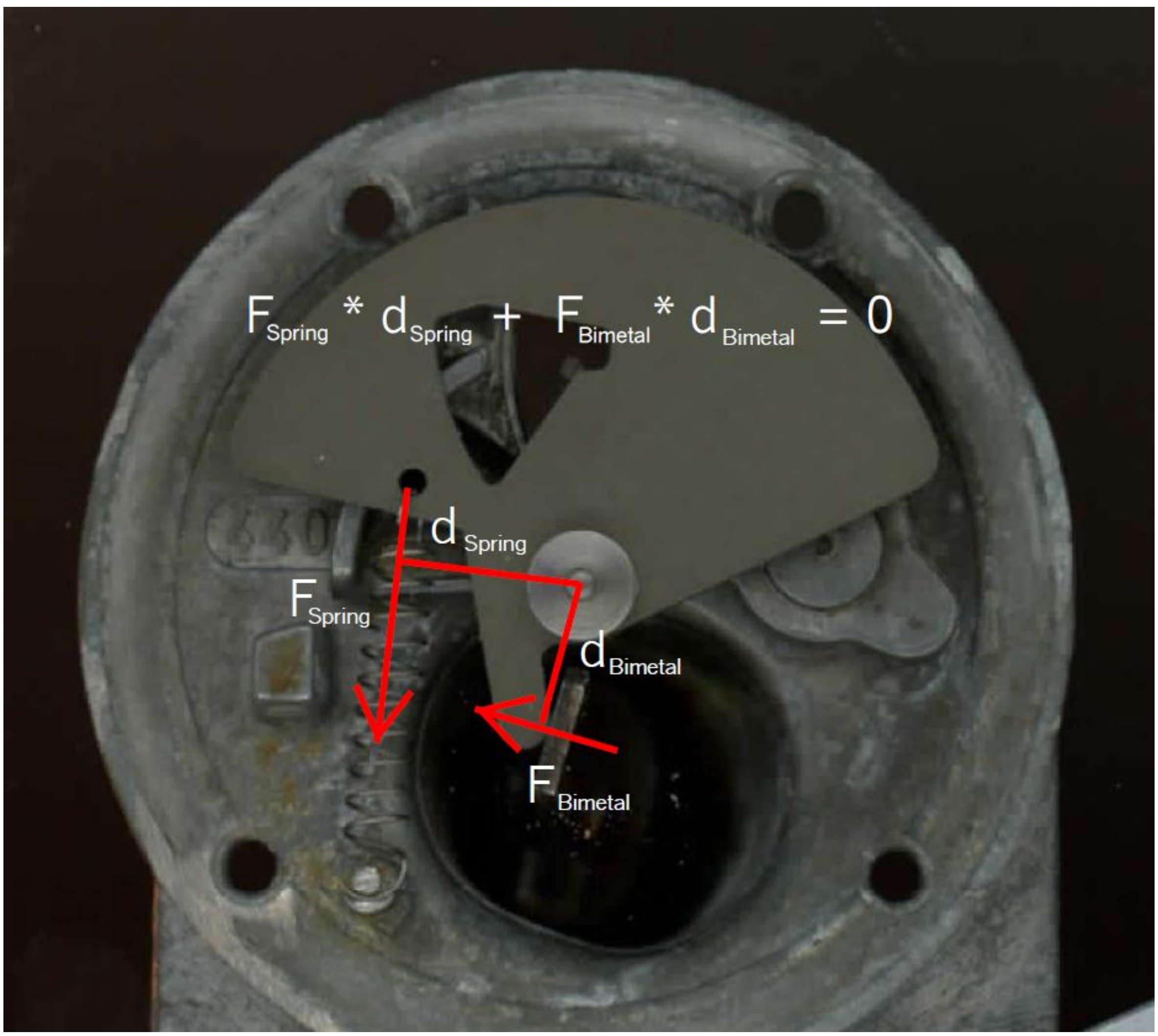
From earlier calculation:

$$l = \sqrt{2r^2(1 - cos\theta) + l_0(l_0 + 2rsin\theta)}$$

$$F_{Spring} = k \cdot \sqrt{2r^2(1 - cos\theta) + l_0(l_0 + 2rsin\theta)} + c$$

Balance of Moments:

For shutter not to move, the sum of all moments needs to be 0.



$$F_{Bimetal} = -\frac{F_{Spring} \cdot d_{Spring}}{d_{Bimetal}}$$

From earlier calculations:

$$m = r \cdot \cos\left(\theta - tan^{-1}\left(\frac{r(1 - cos\theta)}{l_0 + r \cdot sin\theta}\right)\right)$$

$$m = d_{Spring}$$

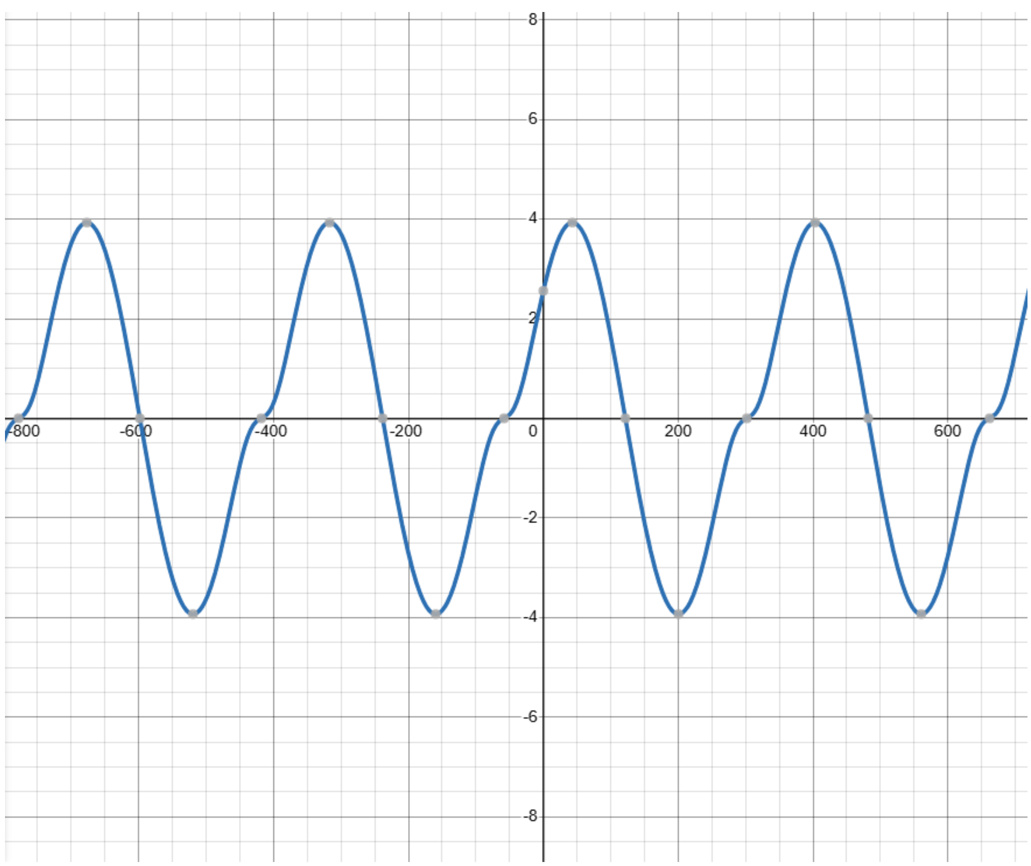
$$F_{Bimetal} = -\frac{(k \cdot \sqrt{2r^2(1 - cos\theta) + l_0(l_0 + 2rsin\theta)} + c) \cdot r \cdot \cos\left(\theta - tan^{-1}\left(\frac{r(1 - cos\theta)}{l_0 + r \cdot sin\theta}\right)\right)}{d_{Bimetal}}$$

$$d_{Bimetal} = 9.14mm,\ r = 10.66mm, l_0 = 17.2mm$$

$$Bosch: k = 2.6730, c = -2.4029$$

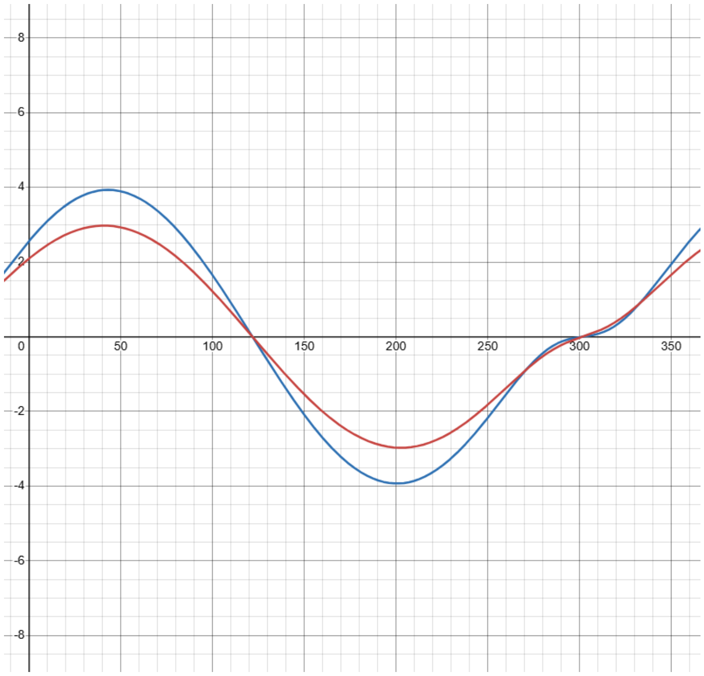
$$Miss.P: k = 184.15, c = -1.3751$$

Resulting function (absolute value of Force):



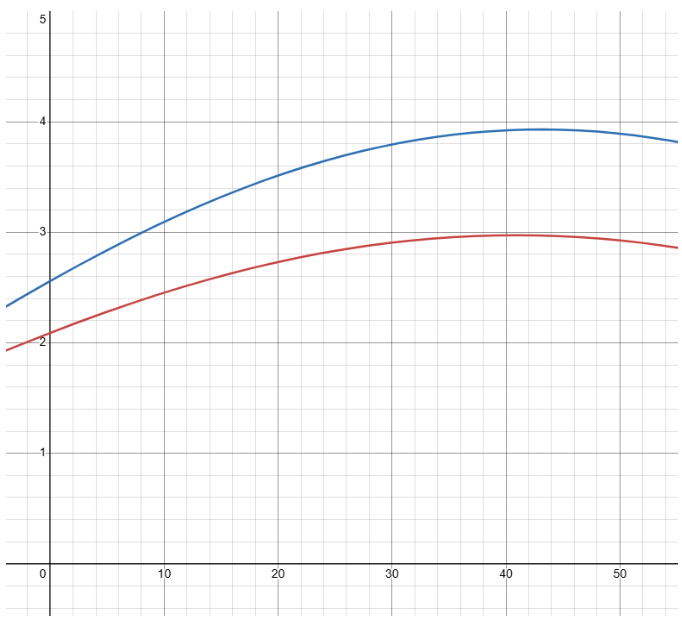
Force on Bimetallic strip in N vs. Shutter angle in degrees from fully closed

About 1 Period



Force on Bimetallic strip in N vs. Shutter angle in degrees from fully closed

Actual Range of AAV ≈ 0 - 50°



Force on Bimetallic strip in N vs. Shutter angle in degrees from fully closed

$F_{Bimetal}$ = 0 - 360° - Max Force = 3.93 N at 43.09° - Bosch - blue

$F_{Bimetal}$ = 0 - 360° - Max Force = 2.97 N at 40.86° - Missing Parts - red

3.93 N correspond to a mass of 401 g or the weight of 13.56 fl oz of water

2.97 N correspond to a mass of 303 g or the weight of 10.25 fl oz of water

Comparison of soft and stiff spring in the same AAV:

Original Bosch Spring at 17°C, 26° angle from fully closed

Missing Parts Spring at 17°C, 34° angle from fully closed

Using the spring from Missing Parts the AAV will be further open at any given temperature improving cold start and driveability during warm up.

Conclusions:

Missing parts Spring is about 2/3 the stiffness of Bosch with spring constants of 267.3 N/m and 184.15 N/m

Convoluted force characteristics on bimetallic strip because of increasing spring force with extension but at the same time reduced moment because of the movement of the spring towards the axis of rotation.

Unlike the ratio of the spring constants (2/3), the ratio of peak force is about 3/4.

Increasing force is exerted onto the bimetallic when the engine gets colder.

Since not fully opening AAVs at cold engine are the ultimate cause of starting problems. Using the softer Missing Parts spring should solve or at least improve cold start.