Pedal Travel Sensor Linkage

The pedal travel sensor is a device that measures the amount of travel of the car's pedal. The information obtained from the sensor can be used to reset engine or other system in the car to enhance the performance and fuel efficiency. A visual inspection was done to evaluate the current performance of the sensor. It was noticed that the linkage from the pedal that rotates the sensor router up to 180 degrees (when the pedal is pushed down all the way) is poorly installed. Afterwards, a simple test on the pedal was implemented couple of times to determine if the current linkage can withstand the buckling effect on it, eventually the linkage broke (See table 2). The scope of this paper is to verify if the new Al 6061 linkage that the team is planning to install is suitable.

The verification process of the aluminum linkage we're planning to use to replace the broken one is straightforward. It started by taking the necessary measurements, such as the distance between the pedal and the sensor router (the linkage length), the diameter of the sensor router which the linkage will be pinned into (The linkage diameter). Afterwards, buckling analysis was done to find the critical load.

The cylindrical linkage will be loaded in compressive such that its length, which is incomparably much greater than its diameter, causes it to experience more than pure compression. When the central loading, caused by the reaction torque produced by the sensor router, reaches the critical load, the linkage becomes unstable, and bending develops rapidly. Therefore, the critical factor of safety will be based on the critical load such that it will be compared with the actual load applied ($n = \frac{P_{cr}}{P}$).

Finally, it's worth mentioning that the current linkage got broken not necessary because of the improper material used, but it might have been because of the improper installation which might have caused the pedal load to act directly on the linkage. The later will break the linkage.

	Pros: -304 Stainless steels have a high elasticity and good for compressive column applications and good -Excellent Corrosion resistance Cons: - Poor cutting performance - Not an actual con, but analysis shows we don’t need use material of that high modulus of Elasticity (E = 200Gpa). Refer to the appendix to check out the analysis Source: https://asm.matweb.com/search/SpecificMaterial.asp?bassnum=mq304a

Table 1: Researched replacement for the broken linkage with pros and cons

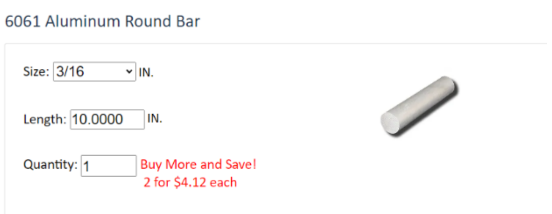
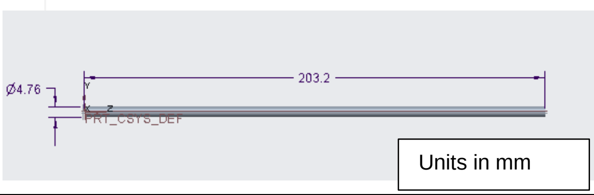
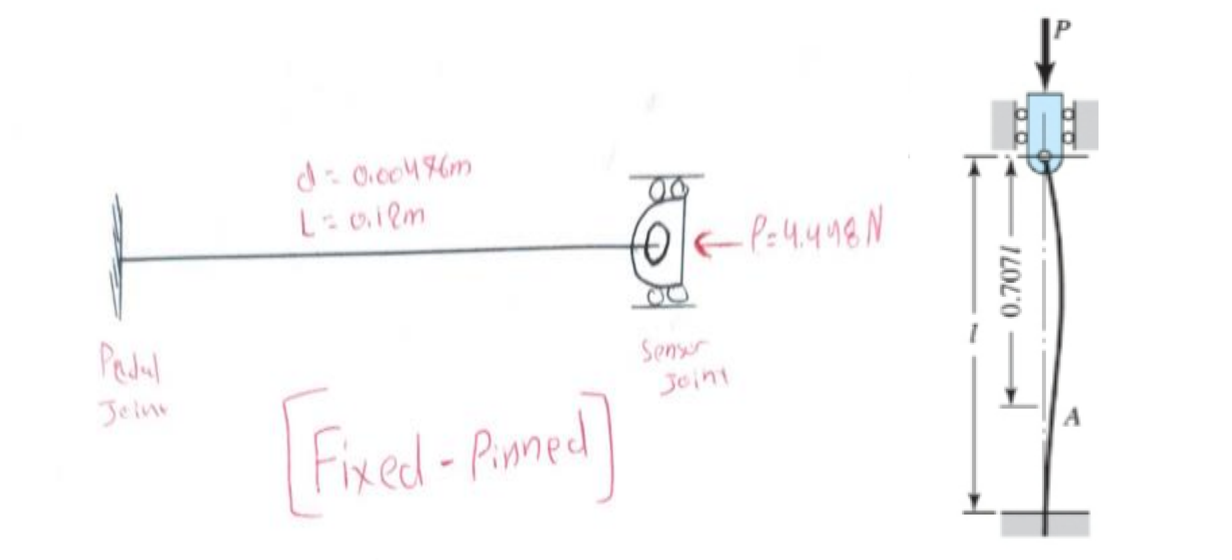
	- The pedal travel sensor is circled in the left. The. Our part of interest is the linkage which is broken as shown in the image. - Dimensions: a) The distance from the pedal joint to the sensor joint is about 8 in (will purchase a 10 in long rod and cut it to the exact length when manufacturing the linkage). b) The diameter of the joint point on the sensor router is 3/16 in (4.762 mm). This will be the diameter of the cylindrical column we are going to analyzed. Note: This is not a design problem (we are not designing for the size required to withstand a given compressive load) because we're already restricted by the router joint point diameter; hence, it's an analysis problem to verify the credibility of using an item that we're planning to purchase.
 	This is the item we are planning to purchase. A 6061 round bar which is widely used form countless applications, including linkages. It has a modulus of elasticity of 69 GPa and a yielding strength of 241 MPa. It's readily available for the given diameter and any customized length.

Table 2: Current setup and design parameters

Buckling Analysis of the Al 6061 linkage:



The above setup shows the linkage loaded in compression. When the applied load (P = 4.448 N) reaches the critical load (which what we will be calculating), the linkage becomes unstable. The critical load depends on the end condition which is, in our case, fixed pin ended column. The linkage is pinned into the sensor joint and fixed into the pedal. The critical load is given as follows:

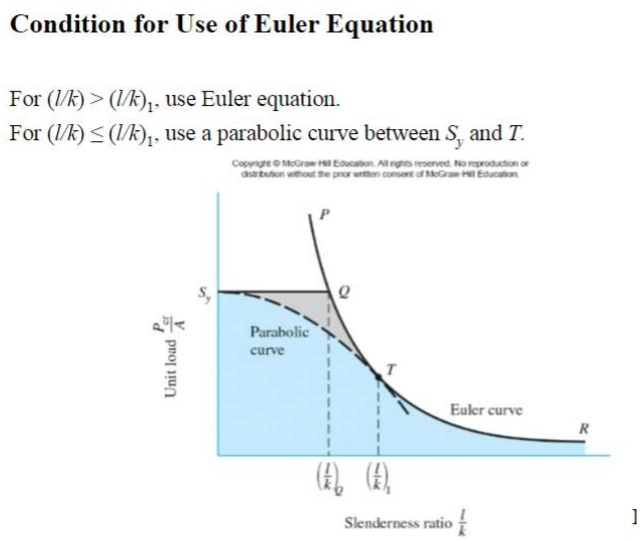
$$P_{cr} = \frac{C\pi^2 EI}{l^2}$$

Notes that the critical load is heavily dependent on the geometry (I: second moment of inertia [I =A*k^2, where k is the radius of gyration and is equal to d/4 for round cross section], L: length of the column). Also, it depends on the material properties which can be seen in the term E (Modulus of Elasticity). We can conclude from the critical load formula that material with high modulus of elasticity can withstand buckling effect more($P_{cr} \alpha E$). The minimum allowable modulus of elasticity was found to be 2.59GPa (Check out the Appendix for the calculations). Moreover, the critical load depends on the end condition which is represented by the term C in the formula.

	End-Condition Constant *C*		
Column End Conditions	**Theoretical Value**	**Conservative Value**	**Recommended Value***
Fixed-free	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$
Rounded-rounded	1	1	1
Fixed-rounded	2	1	1.2
Fixed-fixed	4	1	1.2

For a fixed pinned (Fixed rounded) end condition, substitute 1 for C which is a conservative value and perfect to use when the column load is not known accurately.

There are two equations that could be used to find the critical point, including Euler equation and J.B. Johnson equation. Determining which equation to use depends on the slenderness ratio (l/k) which will be compared to $\left(\frac{l}{k}\right)_1$ as shown below:



Given:

$L = 0.203\ m$ (Length of column)

$d = 0.00476\ m$ (Diameter of the column)

$E = 69\ GPa$ (Modulus of Elasticity for Al 6061)

$S_y = 241\ MPa$ (Yielding strength of Al 6061)

$C = 1$ (Column End conditions fixed-pinned)

$P = 4448\ N$ (Applied centeral load)

$\Rightarrow \frac{l}{k} = \frac{0.203}{\left(\frac{d}{4}\right)} = \frac{0.203}{\frac{0.00476}{4}} = 170.6$ (Slenderness Ratio)

$$\Rightarrow \left(\frac{l}{k}\right)_1 = \left(\frac{2\pi^2 CE}{S_y}\right)^{1/2} = \left[\frac{2 \times \pi^2 \times (1) \times 69 \times 10^9}{241 \times 10^6}\right]^{1/2}$$

$$\left(\frac{L}{k}\right)_1 = 75.2$$

$\therefore$ Since $\left(\frac{L}{k}\right) > \left(\frac{L}{k}\right)_1$ $\therefore$ we can use Euler equation to the critical Load

Since (l/k) = 170.6 was found to be larger than $\left(\frac{l}{k}\right)_1$ = 75.2, Euler equation will be used. For a round cross section column, the Euler formula is given as follows:

$$\frac{P_{cr}}{\pi d^2/4} = \frac{C\pi^2 E}{\left[l/(d/4)\right]^2}$$

Now let's find the critical load based on the given conditions:

Pcr for Round cross section is given as follows:

$$P_{cr} = \frac{C\pi^2 E}{[L/d/4]^2} A = \frac{C\pi^2 E A}{\left(\frac{L}{k}\right)^2}$$

$$\Rightarrow A = \frac{\pi}{4} d^2 = \frac{\pi}{4}(0.00476)^2 = 1.78 \times 10^{-5}\ m^2$$

$$P_{cr} = \frac{(1)(\pi^2)(69 \times 10^9)(1.78 \times 10^{-5})}{(170.6)^2} = 416\ N$$

$$P_{cr} = 416\ N \gg P$$

$\Rightarrow$ Even If we underestimated the applied Load, we have an exteremly comfortable factor of safety

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The critical load was found to be much greater than the load applied which would result in having a large value of factor of safety. Thus, the suggested purchase (the 6061 rod) is applicable and safe to use for manufacturing the Pedal Travel Sensor linkage.

Conclusion

The goal of this paper was to verify the credibility of a suggested purchase (6061 aluminum rod) to use for making the linkage from the pedal travel sensor to the pedal. The verification was approached using buckling analysis in which the critical load was compared to the estimated applied load. It was found that the critical load is much greater than the applied load, and the suggested purchase can be placed. All in all, it seems the buckling effect on the linkage is not that big deal, but the poor installation of the linkage is what needs to be corrected.

Appendix

The following calculations are done to evaluate the minimum allowable modulus of elasticity as well finding what the critical load would have been if the 304 stainless steel rod were used.

⇒ Find the minimum modulus of Elasticity that can be used for: $n_d = 4$, $C = 1$, $L = 0.203\,m$
$d = 0.00476\,m$, $P = 4.448\,N$

$$\Rightarrow P_{cr} = n_d \times P = 4 \times 4.448 = 17.792\,N$$

$$\Rightarrow \text{Slenderness Ration}; \left(\frac{L}{k}\right) = \frac{L}{\frac{d}{4}} = \frac{0.203}{\left[\frac{0.00476}{4}\right]} = 170.6$$

$$\Rightarrow A = \frac{\pi}{4} d^2 = \frac{\pi}{4}(0.00476)^2 = 1.78 \times 10^{-5}$$

$$\Rightarrow \frac{P_{cr}}{A} = \frac{C \pi^2 E}{\left(\frac{L}{k}\right)^2} \quad \therefore \quad E = \frac{P_{cr}\left(\frac{L}{k}\right)^2}{A\, C\, \pi^2}$$

$$E = \frac{17.792 \times (170.6)^2}{(1.78 \times 10^{-5})(1)\,\pi^2} = 2.95\,GPa$$

⇒ The minimum $E = 2.95\,GPa$; this value is valid assuming $\left(\frac{L}{k}\right) > \left(\frac{L}{k}\right)_1$

⇒ Now Lent's see if 304 stainless steel satisfies the Euler equation by finding $\left(\frac{L}{k}\right)_1$; given that E of steel is equal to 200 GPa and $S_y = 215$ MPa

$$\left(\frac{l}{k}\right)_1 = \left(\frac{2\pi^2 CE}{S_y}\right)^{1/2} = \left(\frac{2\pi^2(1)(200\times10^9)}{215\times10^6}\right)^{1/2}$$

$$\left(\frac{L}{k}\right)_1 = 135.5$$

since $\left(\frac{L}{k}\right) > \left(\frac{L}{k}\right)_1$; Euler Equation is valid for 304 stainless steel, and using stainless steel for the given condition is very safe since $E_{304\text{-stainless steel}} \gg E_{minimum}$