

Four Bar Mechanism Project

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Group: 9

ME 2145

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Abstract

This document will cover aspects of 4-bar link design, how 4 bar links are classified, the relationship between coupler curves based on coupler position, and change points. The report also includes multiple mathematical calculation that help describe the 4-bar mechanism.

Classifications and Design

The four bar link mechanism is classified as a Grashof change point Crank-Rocker-Rocker. This classification is derived from when the sum of the largest and the smallest links are equal to the sum of the two-remaining links, and link two which is the smallest is being driven link.

To achieve this mechanical behaviour the following dimensions were chosen. Link one, the ground bar was given a dimension of 10 cm. Link two, the shortest member was assigned a dimension of 5 cm. The largest member used in the four bar was 15 cm which was used as the coupler link and finally link four was given the dimension of 10 cm to complete the assembly.

To verify the classification of the mechanism, please refer to. The combination of the longest and the shortest (15cm+5cm) link is equal 20cm. This matches the total length of the remaining (10cm+10cm) links equal to 20 cm shown in Figure 5 satisfying the Grashof change point Crank-Rocker-Rocker requirements.

The four-bar assembly was designed in SolidWorks and fully 3D printed. Custom 3D printed push pins were designed and 3D printed Figure 4., each pin was pressed fit into the joints of the assembly allowing for full rotational movement. The coupler points were placed in various locations along the coupler link and extra material was added to the mid-section so that a coupler point could be offset in the “Y” direction relative to the bar. No physical bottom link was added as paper was used as the bottom link to complete to full assembly.

Coupler Curves

Coupler Curve #1:

The first coupler point was located 75mm in the x-direction relative link 2. This curve could not be classified due to the change point, therefore it was classified as a double teardrop curve as the shape appears similar to a tear drop coupler curve that has been mirrored. An interesting note is that without the y offset the curves meet at one exact point suggesting that possibly if the y offset was negative, no intersection might be possible. The MATLAB simulation curves matched the physical curves.

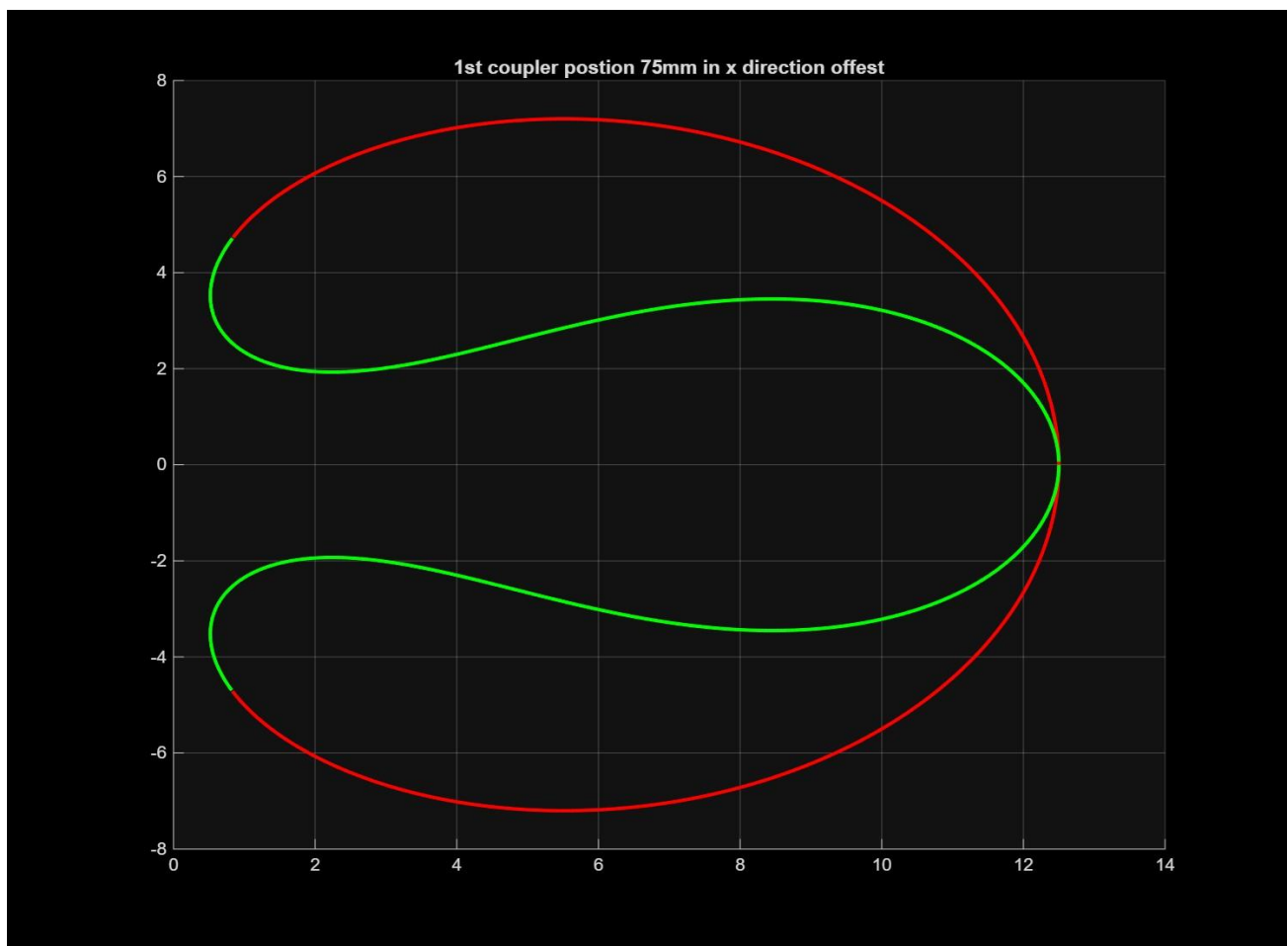


Figure 1 (Coupler Curve #1)

Coupler Curve 2

This coupler point is located 75mm in the x-direction and 25mm in the y-direction relative to link 2. This curve could either be described as an asymmetrical crunode curve or a triple loop due to the centre lines briefly overlapping each other. The overlap is likely due to the offset in the y direction. Further offsets should be tested to get more into the potential relationship between the offset in the y direction and the overlap of the curves. The MATLAB simulation curves matched the physical curves.

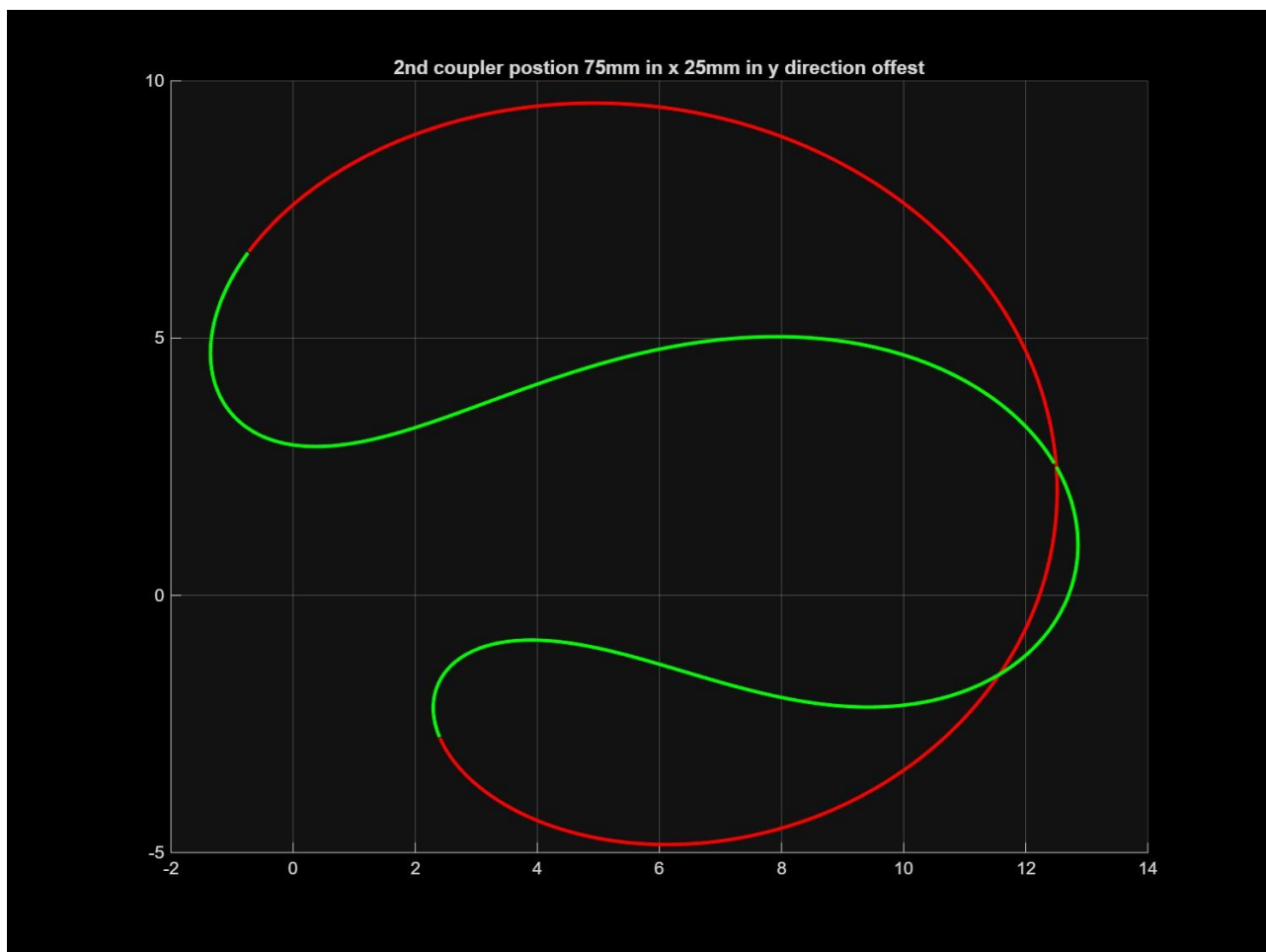


Figure 2 (Coupler curve #2)

Coupler Curve #3:

The third coupler point was located 75mm in the x-direction relative link 2. This curve could not be classified due to the change point therefore it was classified as a double teardrop curve as similar to the first coupler curve the shape appears similar to a tear drop coupler curve that was been mirrored. This coupler curve appears to be narrower than the first coupler curve suggesting a relationship between the distances from link 2 and the width or thickness of the curve. The MATLAB simulation curves matched the physical curves.

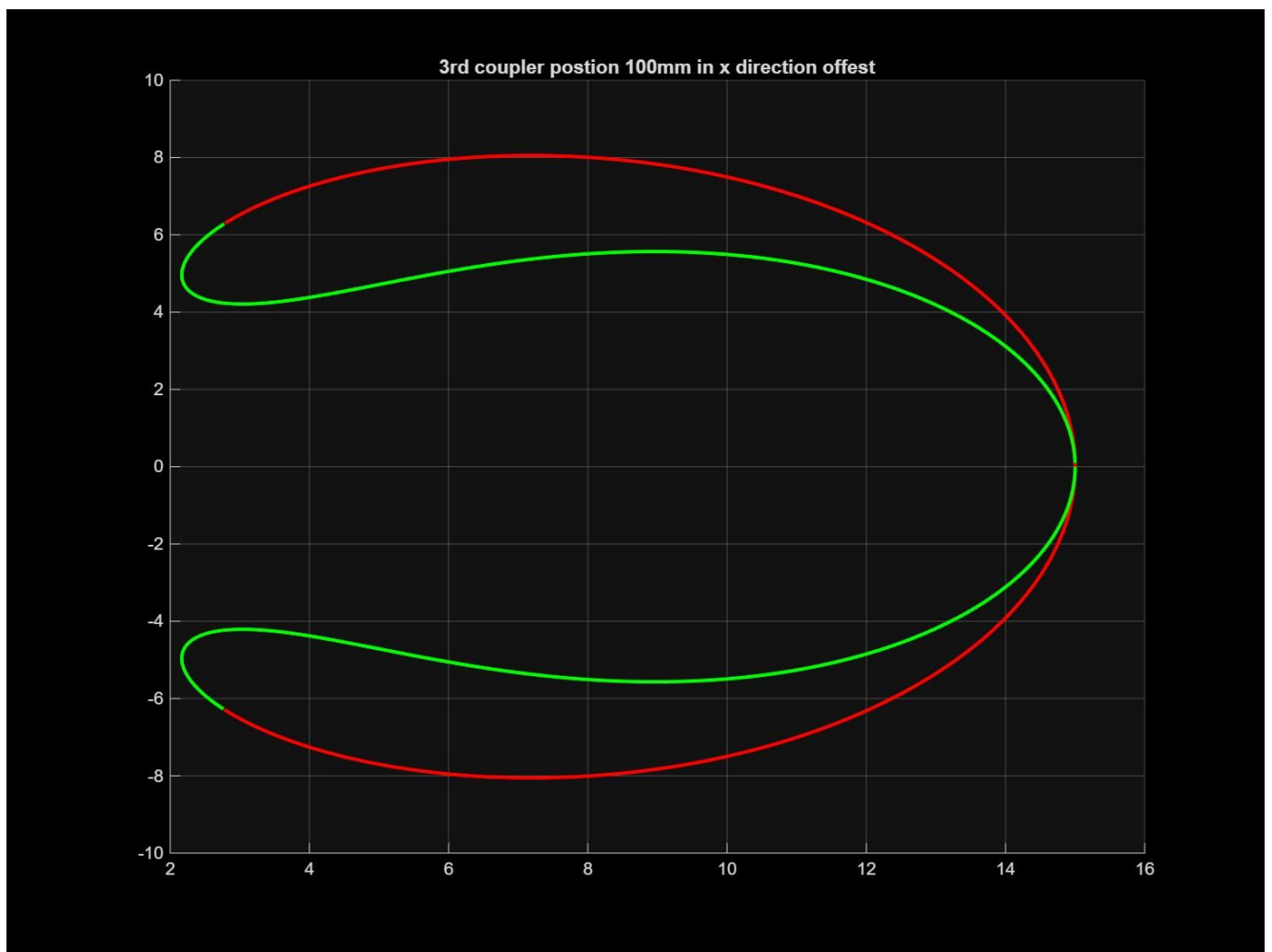


Figure 3 (Coupler Curve #3)

Code

The mat lab code sets the 2nd link set to 50mm to make a full 360-degree rotation using law of cosine to solve the Mechanisms geometry. The coupler points were specified then traced using the X, Y positions using multi-colored curves.

Coupler overall

Overall, the coupler curves that were simulated in MATLAB matched the physical traced curves as seen in Figure 8, and Figure 9. Relationships were found relating the distance of the coupler point in the x direction relative to the 2nd link in which the further the distance the less thick the coupler shape becomes. Whereas the position of the coupler points in the y direction created a overlap at the change point.

Limits of Movement

The limits of motion of the four-bar linkage are determined by the geometry of the mechanism. The classification of the mechanism directly impacts the movement of each link.

Link 2 acts as the input crank and can complete a full 360° rotation. This continuous rotation of link 2 provides the driving motion for the mechanism. Link 4 acts as the output rocker and oscillates between two angular positions rather than completing a full rotation. This occurs due to geometric constraints created by the fixed ground link and the relative lengths of the other links. At the two toggle points, adjacent links approach a nearly mirrored alignment which prevents further motion in that direction. The output rocker reaches its maximum or minimum angular displacement and reverse its direction of motion.

The output rocker follows only a partial arc, and in this case, it had an independent movement of $4\pi/3$ Radians or 240 degrees along the arc. It defines the operational range of the mechanism and impacts the shape of the curves produced. These limits also determine the transition points between different regions of the curves.

Applications

Grashof Crank double Rocker mechanisms are found in many places in our everyday life and can be used in many different applications. The translation from a full rotation to a partial rotation makes the mechanisms very appealing for many applications. One common application is with door closing mechanisms for heavier steel doors. The mechanism may be paired with an electric motor which can open and close the door automatically.

Another common application is in pushrod engines, also known as Overhead Valve engines (OHV). These are typically found in older vehicles as more modern cars typically use overhead cam engines (OHC) for higher efficiency and power. In OHV engines, the camshaft rotates (crank), using the cam lobes to push up the pushrod (rocker), while the pushrod pushes down the rocker arm. The frame of the 4 bar is the engine block.

The final application to be discussed is that of a pumpjack, used in the oil and gas industry. Pumpjacks mechanically lift crude oil from the earth where it is later treated to be used in products. The crank rotates, pushing the pitman arm (rocker) which pushes down the walking beam (rocker), moving the mechanism up and down. The frame of these 4 bars is the physical ground.

Max Transmission Angles, Toggle Point, Change Point Transitions etc.

A toggle position is defined as a specific extreme arrangement in a mechanical linkage where the coupler becomes colinear with either the input or the output link causing zero/infinite mechanical advantage and loss of effective motion. Only two main toggle positions met this criterion for our crank-rocker mechanism (*Figure. 4*) and were observed to be reflections of each other when using the x-axis as the line of symmetry. This indicates that this mechanism is geometrically symmetrical with respect to the ground link.

Both the maximum and the minimum transmission angles occurred when the crank (L2) became colinear with the ground link (L1) as this represents the position when the crank is fully extended or retracted. This can also be seen mathematically through the law of cosines as the length of the bottom of the triangle is either determined as $(L1 + L2)$ or $(L1 - L2)$ leading to dramatically different angles. Note that the minimum transmission angle position shown (*Figure. 5*) is also considered a toggle position as the coupler and output link are colinear.

Change Point Results

An interesting phenomenon took place when the 4 bar was manufactured and tested. Depending on where the force was applied the speed at which the input link moved, and how much force was applied, the 4-bar would take different paths. The same phenomenon takes place when an animation and a simulation in SolidWorks is done, in the animation only a half coupler curve was complete this is because in the animation's things such as mass energy gravity and various other forces are not considered, whereas in a simulation those factors are taken into account which outputs the double coupler curves similar to the ones shown in MATLAB. In the physical model It was found that by applying force with the coupler link would result in the change point double curve.

The dynamic response of the mechanism can vary with the input speed, applied torque and momentum. At lower angular velocities, the coupler points trace the half coupler curve path as the mechanism moved slowly with less inertia meaning it cannot pass through the change point. However, with higher angular velocity and inertia, the crank double rocker pushes through the change point. When the rocker passes through the change points the couplers begin to trace double curve.

This can be directly proven by pushing the 4-bar mechanism using the coupler bar by applying more leverage or driving link 2 with a bit more force to get it past that point.

These results demonstrate that while mechanism geometry defines the fundamental motion constraints, the angular speed can influence the practical motion behavior, inertia, applied torque and visualization of the curves. This highlights the importance of considering both geometric design and operating conditions. It helps to properly analyze mechanism especially near point change configurations where dynamic effects become more significant.

Conclusion

In conclusion, the design, classification, application and the curves obtained from the four-bar mechanism were discussed in this report. The 4-bar mechanism classifies as a Grashof Change Point Crank-Rocker-Rocker mechanism. The 4-bar was designed using SolidWorks and simulated using MATLAB. The manufactured 4-bar model was physically tested, and kinematic analysis was done to ensure the specifications of the mechanism.

The mechanism classification was confirmed using the Grashof Condition which ensured flawless rotation of the input Crank and rotation of the output Rocker between two geometric constraints.

The transmission angles, toggle points and the change point transitions were found using the laws of cosines and geometric laws as shown in Figure 6, Figure 7. The behavior of the mechanism was stimulated and plotted using MATLAB, through physical testing and kinematic calculations, which verified the obtained curves and movement. There are two toggle points which were observed reflections of each other. These points also defined the limit and transitions points for the coupler curves.

There was a relationship observed from the simulations. The curve obtained by applying a y-offset to the coupler points produced an overlapped curve near the change point. An additional relationship found was how the distance of the x-offset is inversely proportional to the thickness of the curve.

Upon physical testing of the mechanism the change point was observed this allowed for 6 different coupler curves, Physical testing showed the how dynamic effects such as inertia and applied force would effect the mechanisms change point behaviour to engage either create half or double coupler curves. The difference in these change points can be observed in the physical coupler tracers shown in Figure 8, Figure 9.

The analysis of this 4-bar mechanism proves the extreme effects that different link sizes coupler position, and drive conditions can have on performance of a 4-bar mechanism. IN addition to proving the importance of the change point which plays an important role in the functionality of the mechanism.

Credits

Syed Shahan Ali: Wrote the topic of limits of movement, change point results and conclusion

Callum Ewen: MATLAB code, 3D print/ solid works design, wrote abstract, classifications and design, formatting, editing, list of figures.

Gabe Arseneau: Wrote applications section, drawing coupler curves, editing

Peter Hebert: Coupler curves, Transmission Angles, Toggle points, and calculations

Citations

[1] R. L. Norton, *Design of Machinery: An Introduction to the Synthesis and Analysis of Mechanisms and Machines*, 3rd ed. New York, NY: McGraw-Hill, 2004, pp. 113-117.

[2] R. L. Norton, "Barker's Complete Classification of Planar Fourbar Mechanisms," in *Design of Machinery*, 3rd ed. New York, NY: McGraw-Hill, 2004, p. 57 (Table 2-4).

[3] R. L. Norton, "Cognates," in *Design of Machinery*, 3rd ed. New York, NY: McGraw-Hill, 2004, pp. 123-126.

[4] "Flywheel - Construction, Working Principle, Types, and Advantages," Testbook. [Online]. Available: <https://testbook.com/mechanical-engineering/flywheel-definition-diagram-and-applications>. [Accessed: Feb. 4, 2026].

Appendix

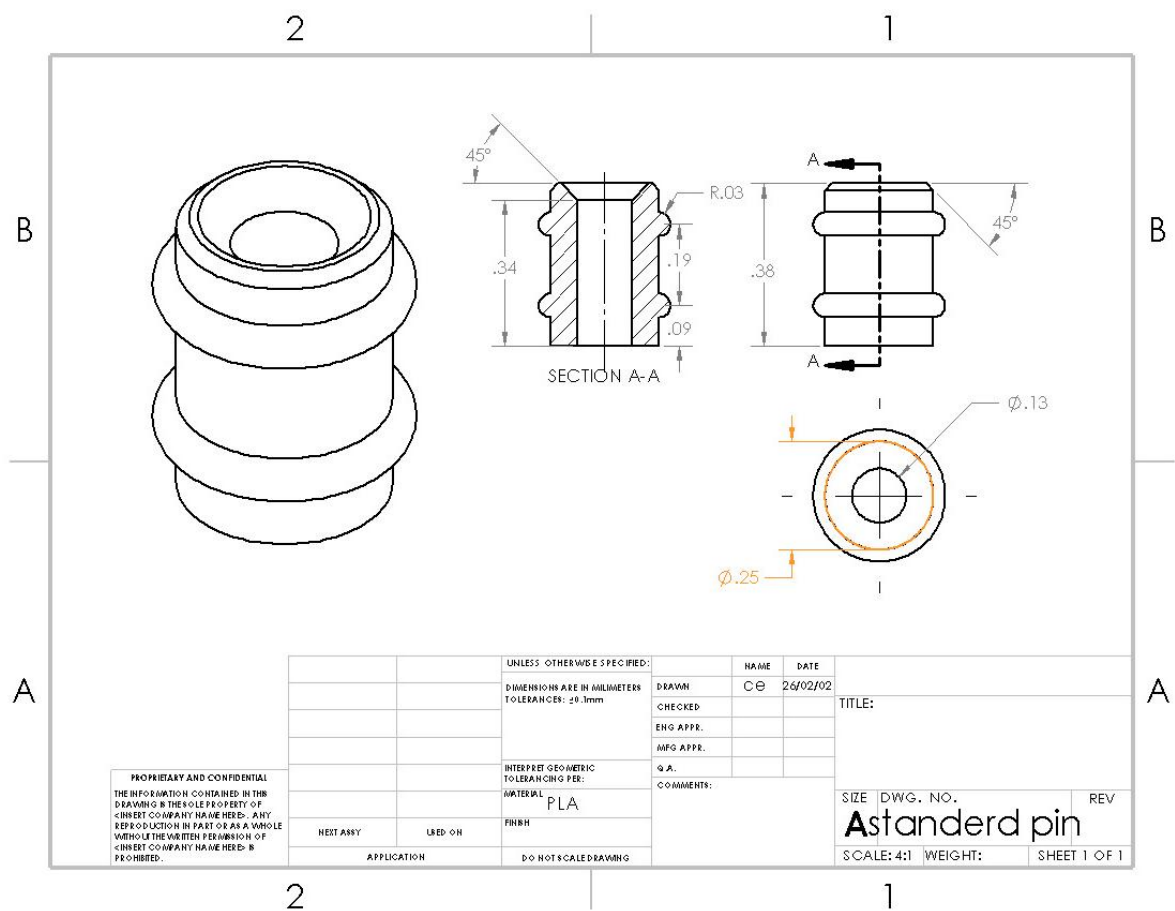


Figure 4 Push Pin CAD Drawing

$L_1 = 100\text{mm } q$		
$L_2 = 50\text{mm } s$	$s+l =$	$p+q$
$L_3 = 150\text{mm } l$	$= 50\text{mm} + 150\text{mm}$	$= 100\text{mm} + 100\text{mm}$
$L_4 = 100\text{mm } p$	$s+l = 200\text{mm}$	$p+q = 200\text{mm}$

$\therefore s+l = p+q$
 L_s driven + smallest s
 $\therefore$ change point
 CLANK rocker rocker

Figure 5 coupler curve Classification mathematics

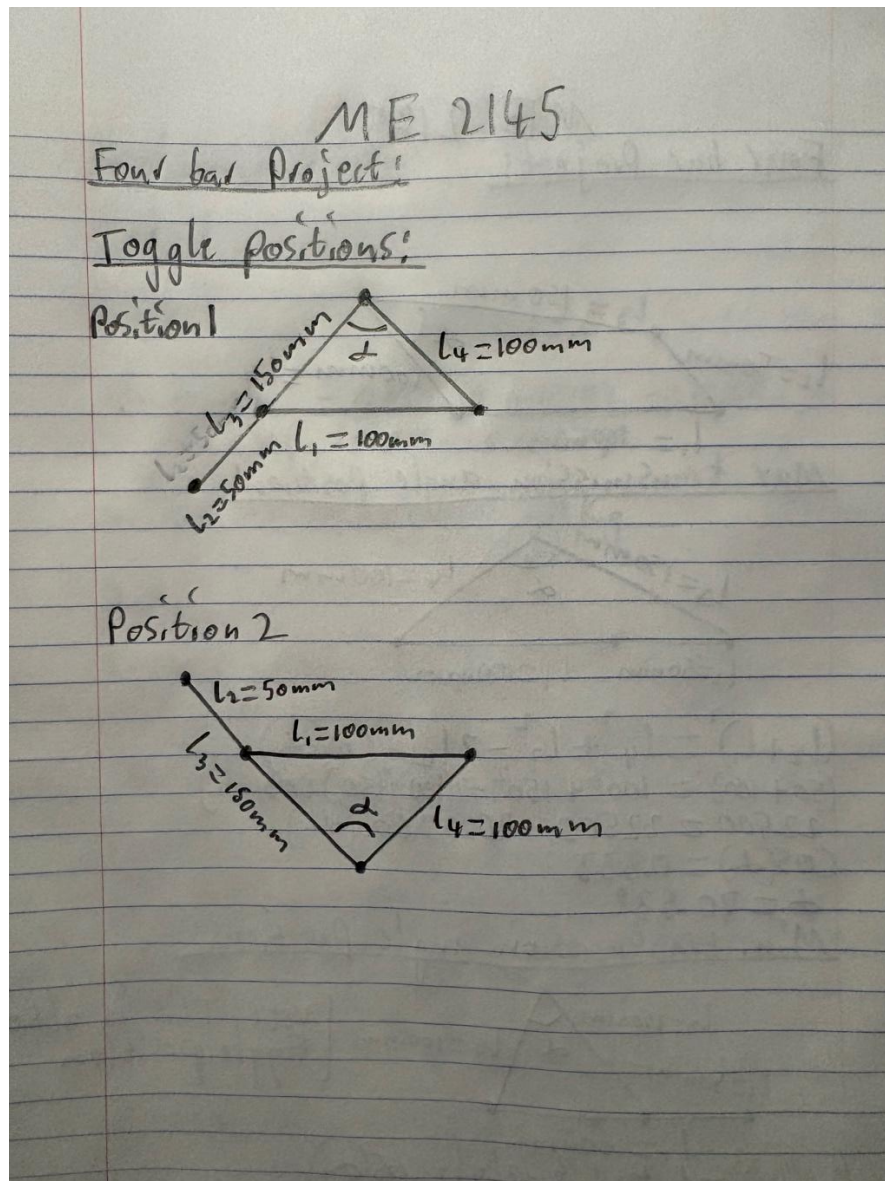
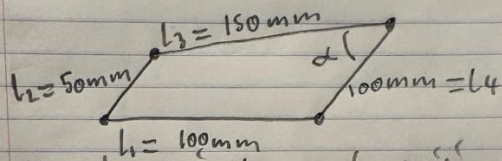
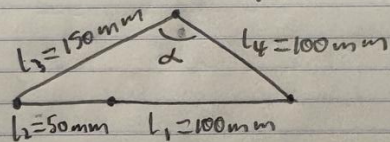


Figure 6 Toggle Positions mathematical proof

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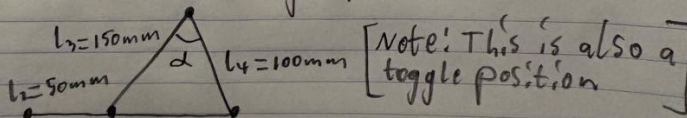


Max transmission angle position:



$$\begin{aligned}(l_2 + l_1)^2 &= l_4^2 + l_3^2 - 2l_4l_3\cos(\alpha) \\ (50 + 100)^2 &= 100^2 + 150^2 - 2(100)(150)\cos(\alpha) \\ 22500 &= 32500 - 30000\cos(\alpha) \\ \cos(\alpha) &= 0.333 \\ \alpha &= 70.53^\circ\end{aligned}$$

Min. transmission angle position:



$$\begin{aligned}(l_1 - l_2)^2 &= l_4^2 + l_3^2 - 2l_4l_3\cos(\alpha) \\ (100 - 50)^2 &= 100^2 + 150^2 - 2(100)(150)\cos(\alpha) \\ 2500 &= 32500 - 30000\cos(\alpha) \\ \alpha &= 0^\circ \text{ or } 180^\circ\end{aligned}$$

Figure 7 Min. and Max. Transmission Angles hand calculations

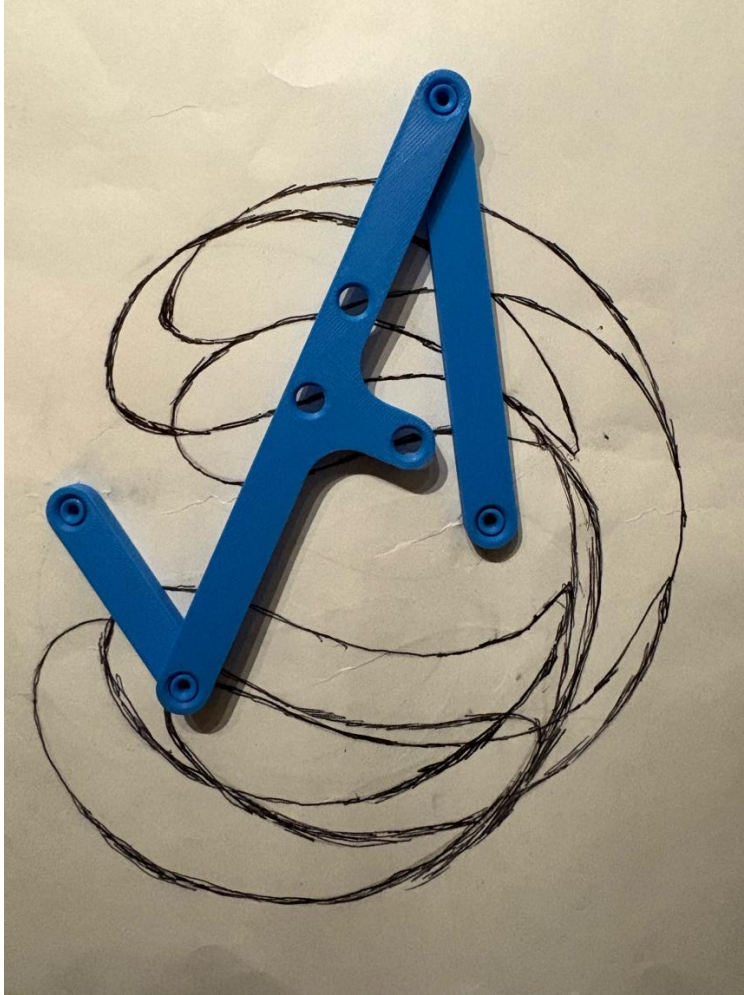


Figure 8 physical model past change point



Figure 9 physical model stopped at change point