Design and Kinematic Analysis of a Two-Sided Asymmetric Scotch Yoke Mechanism with Variable Stroke Lengths

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ABSTRACT

The Scotch yoke mechanism is a device used to change rotary motion into linear motion, usually with equal strokes on each side. This study introduces a modified Scotch yoke mechanism that produces different stroke lengths on each side, making it useful for applications needing varied displacements. The design modeling and motion analysis were completed using SolidWorks to confirm the performance of this asymmetrical stroke. A kinematic study shows how changes in the rotor and yoke design lead to controlled, distinct stroke lengths. This work demonstrates that the adapted Scotch yoke can expand its use in systems requiring precise motion control with varied linear displacements, adding flexibility to its traditional design.

Keywords: Asymmetric scotch yoke mechanism, Variable stroke lengths, Kinematic analysis, Atkinson cycle engine, Solidworks motion analysis

JEL: O31

Introduction

The Scotch yoke mechanism, known for converting rotary motion into linear motion, traditionally delivers equal strokes on each side of its reciprocating path. This design is useful for many industrial applications requiring consistent, linear movements. However, there is a growing need for modified mechanisms that allow controlled, varied strokes to meet specific operational demands, especially in systems where different compression and expansion phases are advantageous. A notable application is in the Atkinson cycle engine, which benefits from an extended expansion stroke relative to the compression stroke, thus improving fuel efficiency (Figures 1–11).

This study presents a customized Scotch yoke mechanism with an innovative feature: asymmetric stroke lengths achieved by varying the offset in the sliderways on either side of the rotor. This design adaptation enables precise control of the reciprocating motion, tailoring the stroke length to meet requirements like those of the Atkinson cycle engine, which relies on differentiated compression and expansion ratios for enhanced performance. Using SolidWorks, we conducted both design modeling and kinematic analysis to verify the behavior and practicality of this asymmetrical configuration.

By adapting the Scotch yoke's traditional design for asymmetric motion, this research expands its applications, particularly in areas requiring controlled displacement variations. The modified mechanism holds promise for energy-efficient systems and opens up possibilities for novel uses in automotive and industrial processes where adjustable stroke lengths contribute to optimized operation.[1,2]

Design and Components

The modified Scotch yoke mechanism presented in this study features a distinct configuration that enables asymmetric stroke lengths on each side of the rotor. This is achieved by varying the offset distances in the sliderways, allowing for customized displacement on each side. The design considerations and primary components of this asymmetric mechanism are as follows:

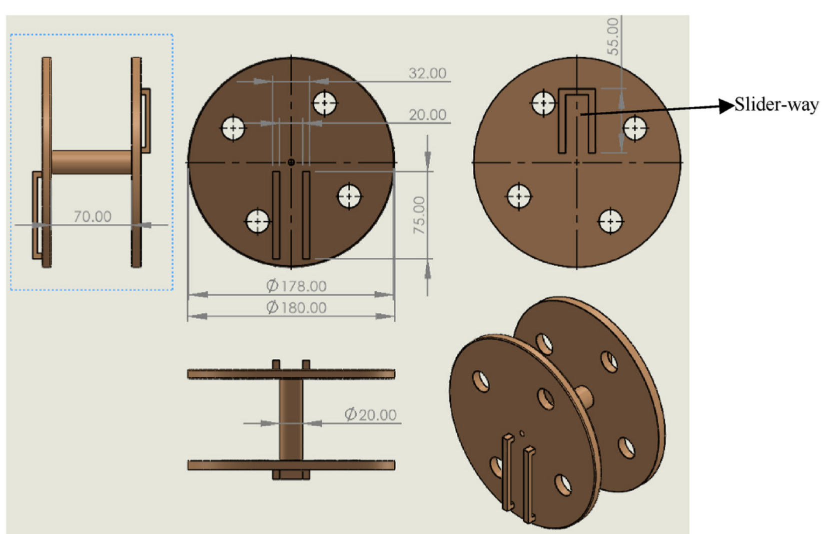

Fig 1 | Rotor

Key Components and Their Functions[3]

Rotor

The rotor is the main rotating component that drives the linear motion of the slider. In this design, the rotor has been adapted to accommodate different offsets in the sliderways on either side. This allows the mechanism to generate variable stroke lengths, with one side achieving a shorter stroke and the other a longer stroke, as per the required specifications.

Slider

The slider translates the rotary motion from the rotor into linear motion along the yoke. The sliderways in the rotor—pathways that guide the slider's motion—are positioned with distinct offsets relative to the centerline of the rotor. By adjusting these offsets, the stroke length on each side of the mechanism varies, enabling asymmetric motion. This configuration is essential to achieving the desired kinematic behavior, especially for applications like the Atkinson cycle engine, where different compression and expansion strokes are advantageous.

Yoke

The yoke connects to the slider and is responsible for translating the linear motion outward to any linked components or applications. It is designed to withstand the forces exerted by the asymmetric strokes, ensuring smooth and controlled linear movements.

Base Frame

The base frame provides structural support and alignment for the rotor, slider, and yoke assembly. It maintains the positional integrity of the components, ensuring consistent motion paths and reducing unwanted vibrations or deviations during operation. The frame's design also supports the sliderway offsets, which are critical for the asymmetrical displacement.

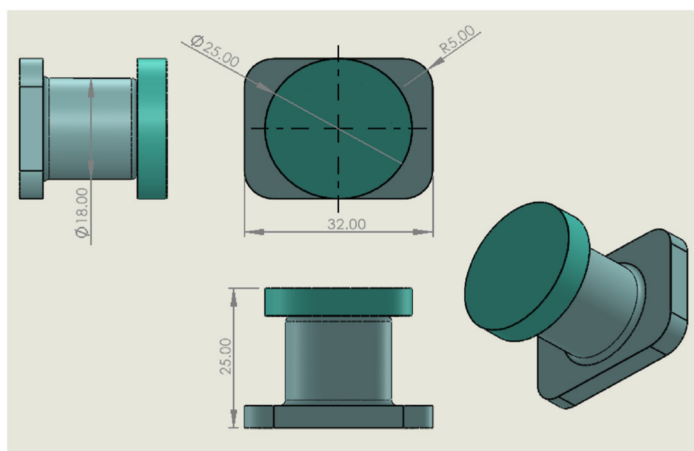

Fig 2 | Slider

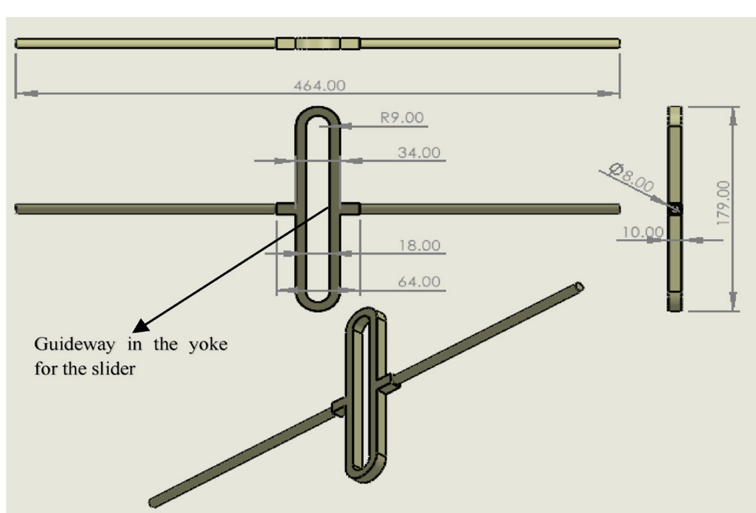

Fig 3 | Yoke

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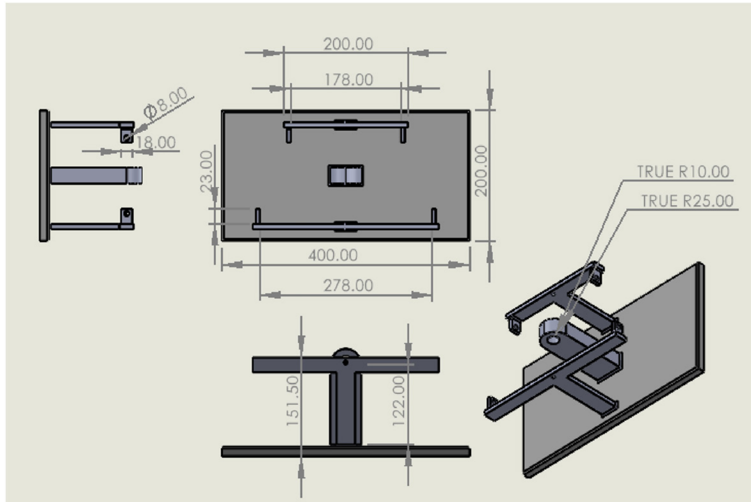

Fig 4 | Base frame

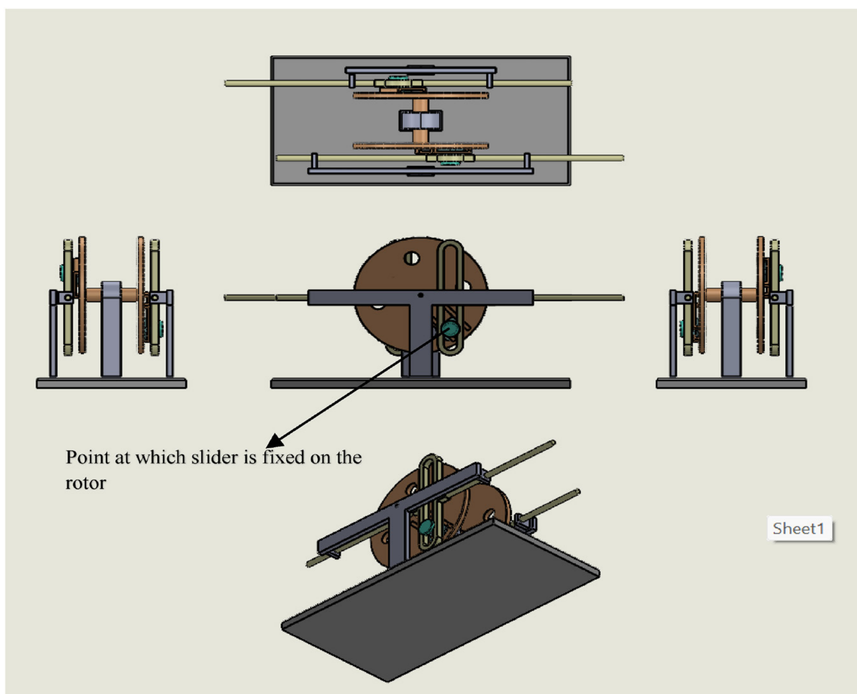

Fig 5 | Assembly

Assembly

Working

(i) The Scotch yoke mechanism is an inversion of the four-bar mechanism.
(ii) As the rotor rotates, the slider moves along the guideway in the yoke, while its position remains fixed relative to the rotor in the sliderway.
(iii) The yoke is restricted from rotating and instead moves linearly along slots provided in the base.
(iv) As shown in the following figure, the point where the slider is attached to the rotor differs on each side, leading to the following characteristics:

In a Scotch yoke mechanism:

- The displacement of the yoke is given by: $x = r \cdot \cos(\omega t)$
- The stroke length is given by: *2r*

where *r* is the distance between the center of the slider and the rotor.

From the above, it is clear that the stroke length on each side is unequal due to the offset.

Motion Analysis Setup[4]

Motor speed: 100 RPM

Gravity: 9806.65 mm/s^2 (in downward direction)

Solid body in contact:

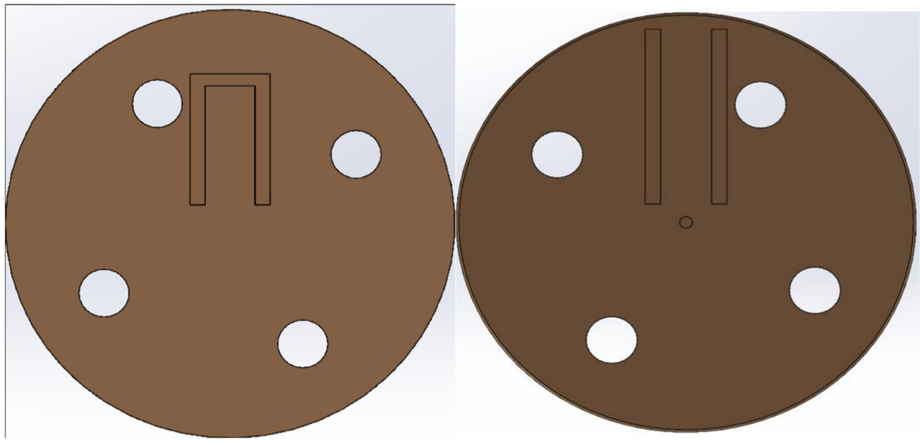

Fig 6 | Comparison of the length of the sliderway on either side of the rotor

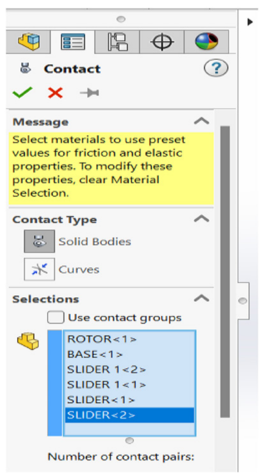

Fig 7 | Solid body contacts

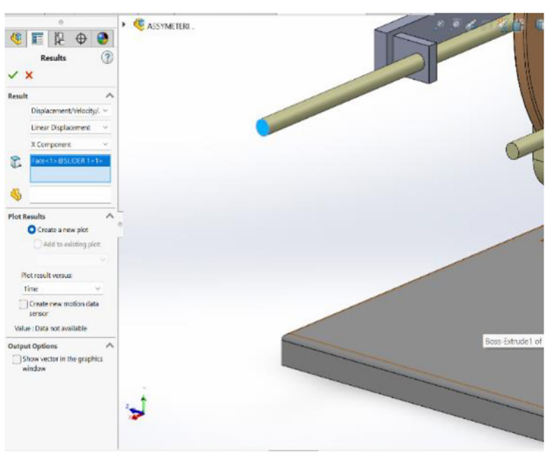

Fig 8 | Specifications for plot 1

Plot specifications:[4]

Motion Analysis Result

Stroke Length

From the above plots, it is clear that:

Stroke length from plot 1: max(plot1)−min (plot1) = 65−(−66)=131 mm

Stroke length from plot 2: max(plot2)−min(plot2) = 45−(−45) = 90 mm

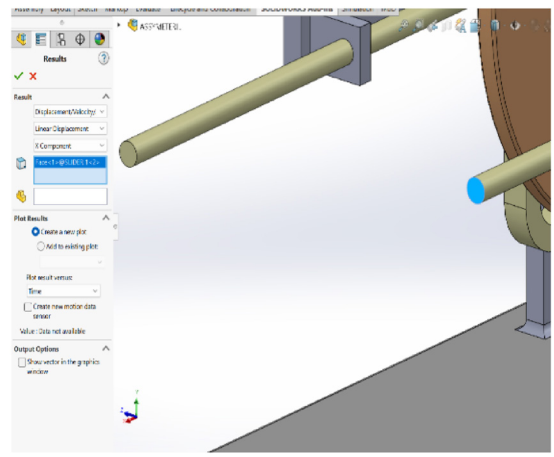

Fig 9 | Specifications for plot 2

Difference in stroke length = 131−90 = 41 mm ≈ 2*(offset) = 40 mm (since offset = 20 mm).

Application

Atkinson Cycle Engines

In an Atkinson cycle engine, different compression and expansion strokes improve fuel efficiency. The asymmetric Scotch yoke mechanism can achieve the varied displacement needed for the different phases, making it suitable for optimizing combustion efficiency in automotive and hybrid engines.

Compressors and Pumps

This mechanism can be used in compressors or pumps that require varying intake and discharge strokes. The ability to customize stroke lengths allows for precise control over compression ratios, enhancing efficiency in fluid transfer systems.

Automation and Industrial Machinery

In manufacturing, automation processes sometimes require actuators that provide distinct displacements for different stages of a cycle. The asymmetric Scotch yoke mechanism can be tailored to provide the necessary range of motion, making it useful in assembly lines or automated systems requiring varied stroke lengths.

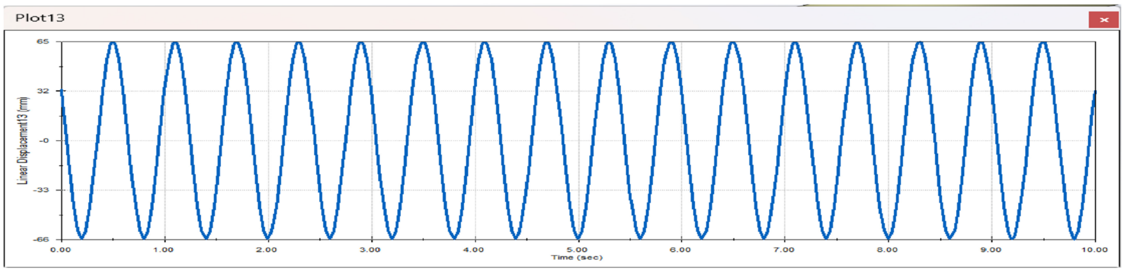

Fig 10 | Plot 1 (linear displacement vs. time)

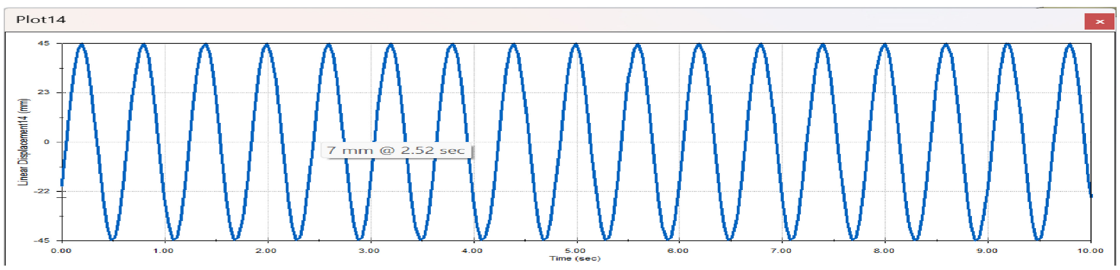

Fig 11 | Plot 2 (linear displacement vs. time)

Limitations

This study presents a modified Scotch yoke mechanism with asymmetric stroke lengths. However, the design currently lacks validation through real-life industrial testing. Further practical experimentation is necessary to confirm the mechanism's effectiveness and reliability in operational environments. This limitation highlights the need for future studies that may focus on structural performance or practical testing in targeted applications.

Conclusion

This study introduces a modified Scotch yoke mechanism with asymmetric stroke lengths, achieved by varying the offset distances in the sliderways on either side of the rotor. The kinematic analysis performed using SolidWorks demonstrates that this design effectively produces distinct stroke lengths on each side, offering potential advantages for applications requiring variable displacements, such as Atkinson cycle engines and certain automation systems.

Through detailed motion analysis, we have validated the mechanism's capability to achieve controlled, asymmetric motion, expanding its functional possibilities in fields where customized reciprocating motion is needed. This work provides a foundation for further research into similar modifications, with future studies potentially examining structural performance or practical testing in targeted applications.

Competing Interest Statement

The author declares that there are no competing interests related to this research. The author has no financial, personal, or professional affiliations that could be perceived to influence the work presented in this manuscript. Declaration of generative AI and AI-assisted technologies in the writing process.

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