ME 5250: Robot Mechanics and Control
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Project-1: Six-Bar Torque Amplifier

Report By

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Problem Statement

Explore 6-bar mechanisms (or related mechanisms) to try and create a large rotational to rotational mechanical advantage. Imagine, say, that you have a motor and want to achieve a large speed reduction/torque increase with a 6-bar (or similar) linkage mechanism, instead of using gears. You might want to do this if you want to eliminate all backlash from the system. A simple 4-bar crank-rocker can achieve only a limited gear ratio and a modest range of motion. Use your judgment to develop a design or a couple of designs that use 6-bar (or more complex) mechanisms that attempt to balance the desire for a large range of motion, a large gear ratio, and linearity of the transmission.

Explanation

Introduction:

Traditional gear systems remain a cornerstone of mechanical power transmission, offering well understood design principles and reliable operation. However, inherent backlash, a source of noise and positional inaccuracies, limits their suitability for high-precision applications. This report explores the potential of 6-bar linkages as a viable alternative for achieving high mechanical advantage including significant speed reduction and torque multiplication while eliminating backlash

This investigation is driven by the need for a mechanism that optimizes the following key performance indicators:

1. *High Gear Ratio (velocity Reduction):* A substantial decrease in the output shaft's rotational speed compared to the input motor. This can be quantified by the ratio of input to output angular velocities.
2. *Large Torque Amplification:* A significant increase in the output torque relative to the input torque. This can be expressed as the ratio of output torque to input torque.
3. *Wide Range of Motion (Output Angular Displacement):* The ability of the output shaft to undergo considerable angular displacement while maintaining functionality. This is measured in degrees or radians.
4. *Linear Transmission (Constant Velocity Ratio):* Ideally a constant ratio between the input and output angular velocities throughout the entire range of motion. This ensures predictable and smooth operation.

Simple 4-bar crank rocker linkages, while widely used, offer limited gear ratio and range of motion. This report delves into the domain of 6-bar linkages, proposing one design configuration that attempt to achieve a balance between the aforementioned key performance indicators. We will explore the following:

1. *Kinematic Analysis of 6-Bar Linkages*: We will analyze the kinematics of 6-bar linkages to understand the relationship between input and output motion for various configurations. This analysis will involve concepts like Gruebler's equation for determining degrees of freedom and applying DH parameters for kinematic modeling.
2. *Design Considerations for High Mechanical Advantage*: We will delve into the design considerations for 6-bar linkages to achieve high gear ratio and torque amplification. This will involve exploring parameters like link lengths, joint locations, and coupler curve characteristics.
3. *Balancing Range of Motion and Linearity*: We will investigate the inherent trade-offs between achieving a wide range of motion and maintaining a linear transmission ratio. This may involve exploring variable-geometry linkages or introducing additional constraints for specific applications.

Literature Survey:

[1] Optimized five-bar linkages with non-circular gears for exact path generation. In this paper, a five-bar linkage with non-circular gears is proposed as a mechanism capable of precisely moving a coupler point along a prescribed trajectory. The first step of the proposed methodology is the inverse kinematic analysis of the linkage, whose mobility, without geared bodies, is two. Therefore, by imposing the required configuration of the coupler at any instant, the rotation of the two inputs is evaluated.

[2] The Kinematic Synthesis of spatial Six-bar Mechanisms: This paper provides a new methodology for the kinematic synthesis of spatial linkages constructed from six links and seven spatial joints, known as spatial six-bar linkages. Kinematic synthesis uses the required movement of components of the linkage to define geometric constraint equations that are solved to determine the dimensions of the links, also known as dimensional synthesis. Here a new methodology for the dimensional synthesis of spatial six-bar linkages is introduced that combines robotics with the kinematic synthesis of spatial constraints.

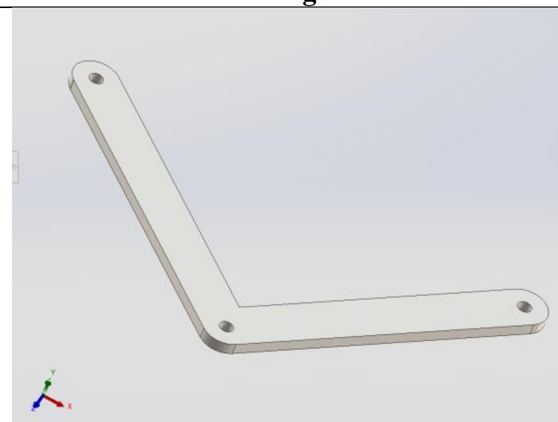
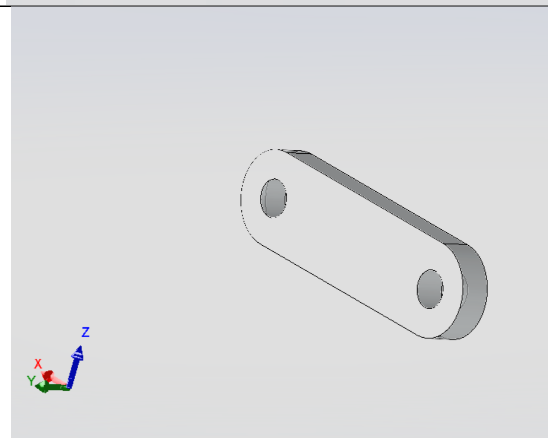
[3] Kinematic and Dynamic Analysis of Stephenson Six Bar Mechanism Using HyperWorks. This paper highlights the usefulness of Altair HyperWorks in kinematic and dynamic analysis of multibody (MBD) systems such as mechanisms. A mechanism in motion transmits forces and moments to the ground known as shaking force and shaking moment which are responsible for vibrations and fatigue. From the design point of view, these quantities are very important and variations in them for a complete cycle of motion can be easily found out using HyperWorks. A MBD simulation with rigid bodies was carried out for Stephenson six bar mechanism using MotionSolve whereas MotionView was used for modeling the mechanism. The results were generated by HyperGraph

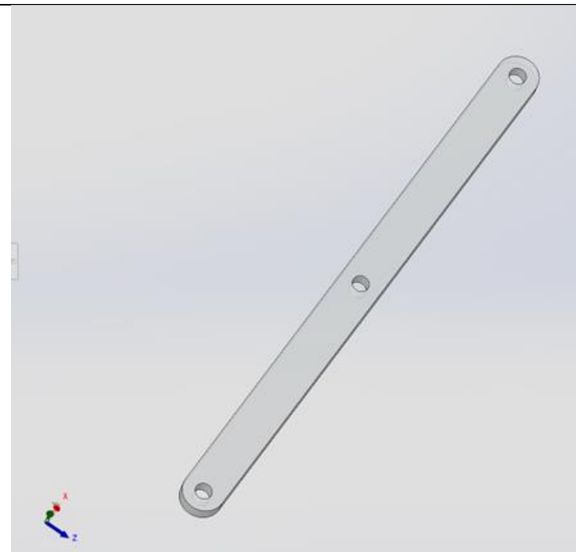
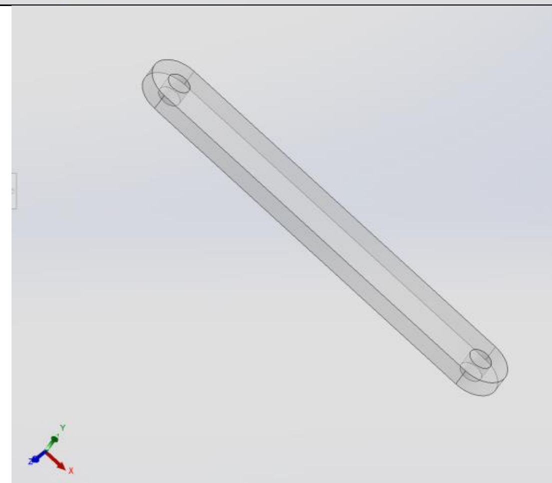
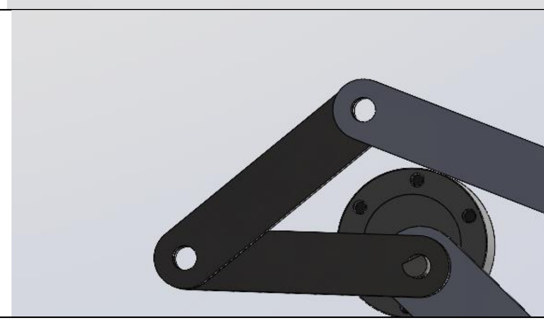
Here the first and second paper talks about the kinematics of 6 bar and 5 bar mechanisms and how we can improve them. Later they also talk about gear reduction as well as redundant kinematics of the mechanism. The third literature is about 6 bar linkage mechanisms, which convert rotatory motion of input to oscillatory motion in input with increased torque. The stephension six-bar working mechanisms have higher mechanical advantage and better dwelling characteristics, reducing capacities and costs of servo motors effectively.

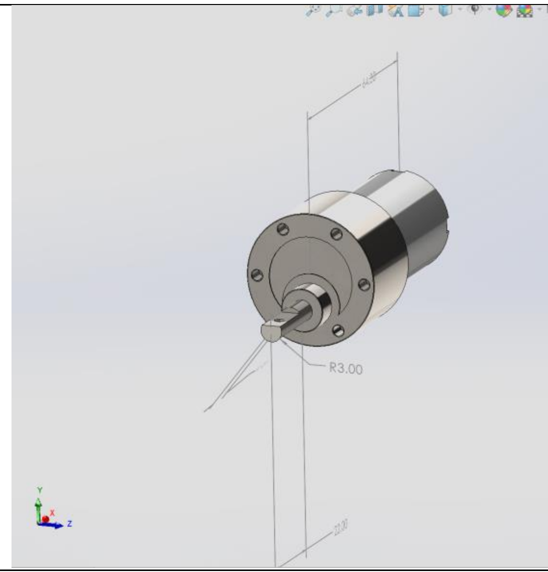
The mechanism that we have used in this project is a combination of 6 bar linkage as well as a servo motor to achieve higher torque and low velocity.

Mechanism:

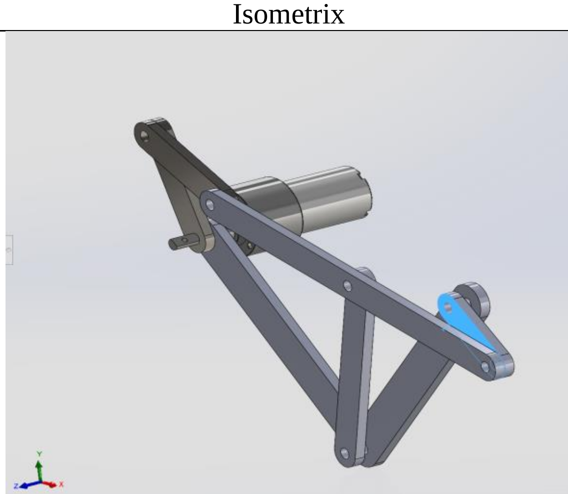
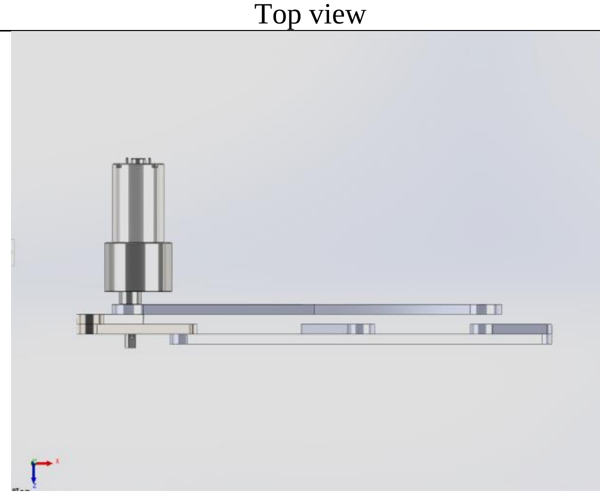
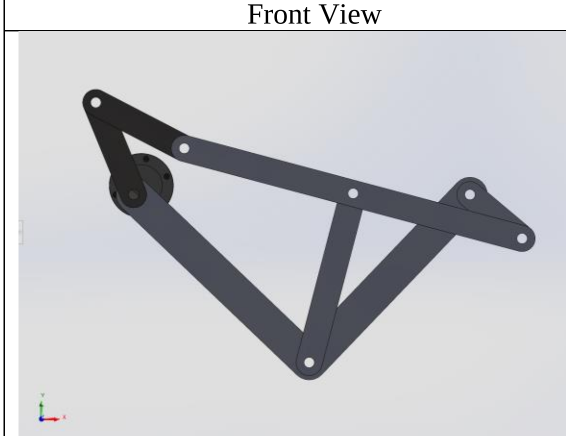
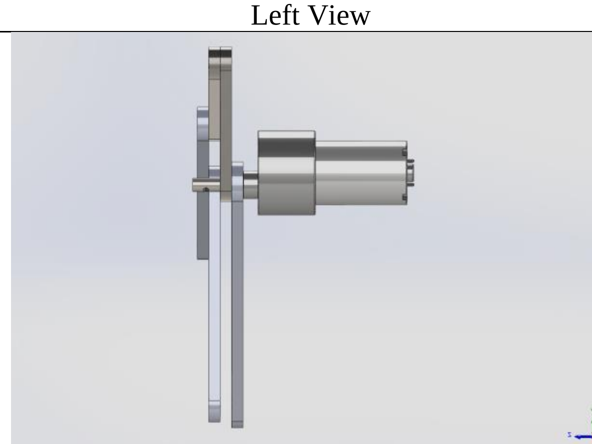
Our chosen design leverages the ingenuity of the Stephenson six-bar linkage, a powerful configuration known for its versatility in achieving complex motion profiles. This linkage comprises six bars connected by seven joints, offering one degree of freedom. Here's a breakdown of its components:

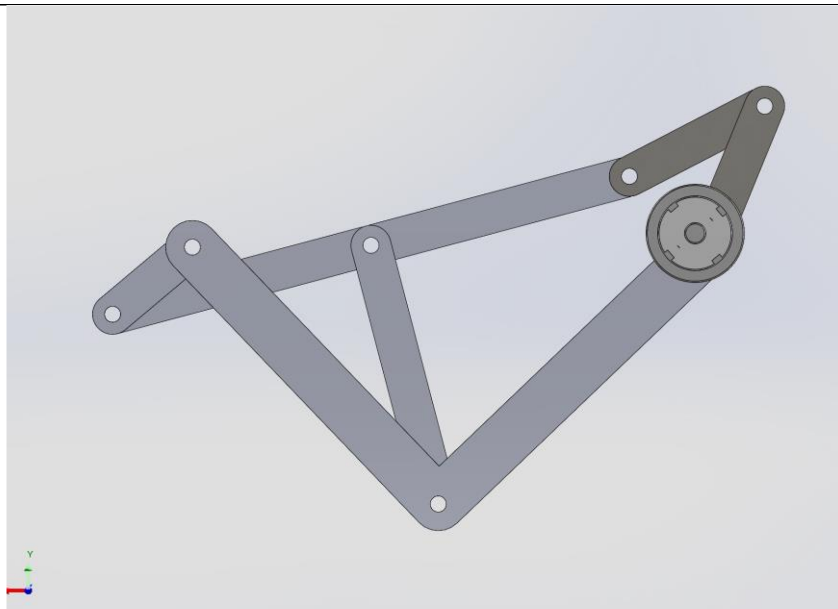
Component	Image
1. *Fixed Base Bar (Ground Link):* This stationary bar provides a stable reference point for the mechanism.	
2. *Input Crank:* This bar receives rotational input from the motor, initiating movement within the linkage	

3. *Coupler link:* Often the longest bar, this link connects the input crank to the output link and plays a crucial role in defining the output motion.	
4. *Rocker:* This bar acts as a pivot point, influencing the trajectory of the coupler link.	
5. *Output link:* This set of bars transmits the final rotational motion to the desired application	

6. Servo Motor	

Connecting the above components to form an assembly, our mechanism will look as below.

Isometrix	Top view
	
Front View	Left View
	

Back view


Mobility Analysis:

The mechanism has 6 links, 1 motor and 7 joints.

Number of links (N) = 7

Number of joints (J) = 7

Independent Freedoms Σf_i = 7

M = 6 (Spatial)

By grubler's equation:

DOF = m(N – 1 – J) + Σf_i = 6(7 – 1 – 7) + 7 = 1 (which is appropriate for this mechanism)

Kinematic Analysis:

The input link is connected with the base link which connects the connection coupler, end effector, motor and connecting link. When the input link is rotated the output link is also rotated hence actuating the motor resulting in torque amplification and velocity reduction. Keep in mind that the rotational directions are opposite on both ends.

There are no singularities in this mechanism as there is only 1 degree of freedom.

Mechanism Methodology:

The range of motion of this six-bar linkage is highly customizable. By adjusting the link lengths and joint locations, we can tailor the design to achieve a wide range of angular displacement in the output link. This allows us to meet the project's requirement for expansive motion capabilities.

Linearity of transmission, however, can be a challenge in 6-bar linkages. While this design offers a wider range of linear operation compared to some other configurations, there may still be slight variations in the output speed throughout its motion. To address this, we can explore techniques like incorporating additional linkages or introducing variable-geometry elements that adjust the transmission ratio during specific points in the cycle.

During the design process, we considered potential size constraints and packaging limitations. The Stephenson six-bar linkage offers some flexibility in how the bars are arranged, allowing us to optimize the overall footprint of the mechanism while still achieving the desired functionalities.

By carefully selecting link lengths, and joint locations, and potentially incorporating additional features, the Stephenson six-bar linkage provides a promising platform for achieving our project objectives: significant speed reduction, amplified torque, expansive range of motion, and a reasonable degree of transmission linearity. Further analysis and optimization can refine this design for specific applications.

Below is a recorded video of the mechanism in motion:

https://youtu.be/mRzURNDtzmI

Conclusion:

This project has helped us explore the potential of 6-bar linkages, specifically the Stephenson six-bar design, as a viable alternative to traditional gear systems for achieving high mechanical advantage. The design demonstrates the ability to achieve significant speed reduction, amplified torque, and a wide range of motion, overcoming the limitations of simpler 4-bar crank-rocker linkages.

While achieving perfect linearity of transmission remains a challenge, the Stephenson six-bar linkage offers a promising starting point. Further exploration of additional linkages, variable-geometry elements, and advanced kinematic analysis can potentially improve this aspect.

The key takeaway from this project is the exciting potential of 6-bar linkages for applications demanding high mechanical advantage with minimal backlash. This opens doors for quieter, smoother, and more precise control in various fields, from robotics and automation to medical devices and high-performance machinery.

References

- M. S. Erden, I. K. Ahamed, and A. G. Ulsoy, "Kinematic and Dynamic Analysis of Stephenson Six Bar Mechanism Using HyperWorks," *ResearchGate*, [Online]. Available: https://www.researchgate.net/publication/271191554_Kinematic_and_Dynamic_Analysis_of_Stephenson_Six_Bar_Mechanism_Using_HyperWorks (accessed: Mar. 21, 2024).

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