Design And Fabrication of 3D Printed Elleptical Trammel Mechanism

M Rajesh[1], S MD Shahid[2]
[1, 2]Government Polytechnic College-Anantapur: 515001, A.P

Abstract- *This project explores the design and fabrication of an Elliptical Trammel (Trammel of Archimedes) using Fused Deposition Modeling (FDM) to demonstrate the inversion of a double slider-crank chain. The mechanism, which translates constrained linear motion into a precise elliptical trajectory, was digitally modeled via CAD software with a specific focus on parametric geometry, including a semi-major axis of 136.5 mm and a semi-minor axis of 84 mm.*

The components were fabricated using Polylactic Acid (PLA) on a QIDI TECH Q1 Pro 3D printer, utilizing a 0.2 mm layer height and 20% grid infill to balance structural rigidity with production efficiency. Critical attention was paid to dimensional tolerances (0.2 mm to 0.4 mm) to ensure smooth slider-to-track interaction and minimize mechanical backlash. The final assembly, completed in 2 hours and 29 minutes, validates the effectiveness of additive manufacturing for rapid prototyping and low-cost educational tools. This work serves as a functional benchmark for kinematic analysis and illustrates the practical application of 3D printing in mechanical engineering education.

Keywords: elliptical trammel, trammel of Archimedes, double slider-crank chain, 3D printing, FDM, mechanical linkage, kinematics

I. INTRODUCTION

The elliptical trammel mechanism, also known as the Trammel of Archimedes, is a classical mechanical linkage used to generate a perfect elliptical path. It consists of two sliders moving in mutually perpendicular grooves and connected by a rigid link. As the link moves, any selected point on it traces an ellipse, making the mechanism an important example in the study of kinematics, constrained motion, and path generation in mechanical engineering.

This project focuses on the design and fabrication of a 3D printed elliptical trammel mechanism using Fused Deposition Modeling (FDM). The mechanism is significant not only for its simple construction and precise motion but also for its educational value in demonstrating the inversion of a double slider-crank chain. By adopting 3D printing technology, the project provides a cost-effective and practical approach for developing a functional prototype that can be easily modeled, manufactured, and assembled.

The project also examines important practical factors such as dimensional accuracy, printing tolerances, surface finish, and smooth sliding action, all of which influence the performance of the mechanism. Thus, the 3D printed elliptical trammel mechanism represents a useful combination of classical mechanism theory and modern manufacturing technology,

II. LITERATURE REVIEW

The Elliptical Trammel, or Trammel of Archimedes, is a classical inversion of the double slider-crank chain that generates precise elliptical paths through two perpendicular sliders. Its straightforward geometric behavior makes it a foundational example in kinematics for demonstrating exact path generation in machine design.

Traditionally used as drafting instruments, modern trammels now serve as motion generators and educational models. Digital tools like computer-aided modeling have significantly enhanced the ability to analyze and optimize these mechanisms' functionality before fabrication.

Additive manufacturing, specifically Fused Deposition Modeling (FDM), offers an accessible and economical method for producing these linkages directly from CAD data. This approach allows for rapid prototyping and easy customization of trammel dimensions, supporting iterative design for educational and low-load applications.

Performance in 3D-printed linkages is often challenged by surface roughness, anisotropic strength, and frictional wear between moving parts. To prevent binding or irregular motion, designers must prioritize precise printer calibration, strategic part orientation, and calculated mechanical tolerances.

PLA is the preferred material for these prototypes due to its stiffness and low cost, though its brittleness and wear resistance must be managed. High-quality operation is achieved by reinforcing stressed regions, smoothing contact surfaces, and ensuring proper clearance in the slider-groove assembly.

Research Gap and Need for the Present Work

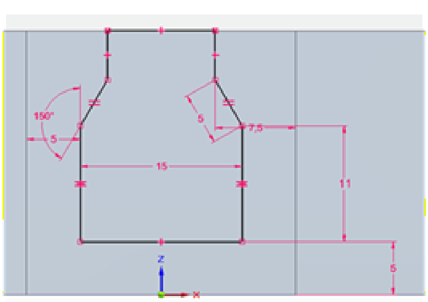
"The classical studies extensively detail trammel geometry, a significant ***research gap*** *exists in the development of low-cost, 3D-printed versions for educational use. Furthermore, there is a lack of focused literature on the specific performance of FDM-printed linkages involving continuous sliding contact, leaving the intersection of mechanism theory and practical additive manufacturing largely unexplored.*

The ***novelty*** *of this work lies in the integrated design and evaluation of an FDM-fabricated trammel, proving that functional path-generating models can be produced economically without sacrificing kinematic accuracy. This research uniquely contributes to the field by quantifying how specific 3D printing parameters and material-specific tolerances directly influence the operational performance of classical mechanical linkages".*

III. METHODOLOGY:

Modeling and Preparation Process :

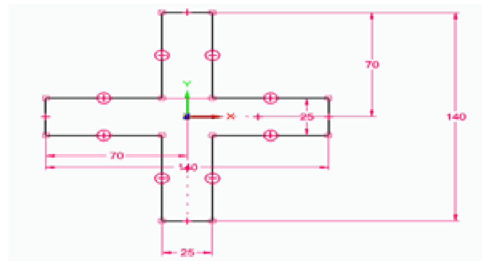
a. **Parametric Modeling:** The team used equations and mathematical formulas to define the mechanism's geometry. This approach allowed for easy adjustments to design parameters—such as the semi-major axis ($a = 136.5\text{ mm}$) and semi-minor axis ($b = 84\text{ mm}$)—to customize the size and eccentricity of the resulting ellipse.



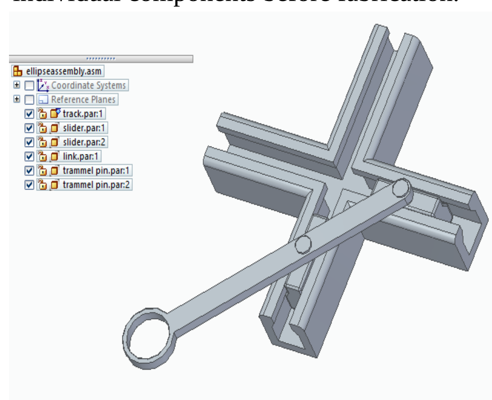
Parametric Geometry Constraints

The "novelty" of your design lies in its parametric setup. You must explicitly state the dimensions that govern the elliptical path to allow for reproducibility:

- **Semi-Major Axis (a):** 136.5 mm
- **Semi-Minor Axis (b):** 84 mm
- **Mathematical Model:** $x = a \cos(\theta), y = b \sin(\theta)$.
- **Clearance/Tolerance:** 0.2 mm to 0.4 mm (Crucial for FDM publications to show how you handled material expansion).



b. **Assembly Modeling:** An assembly model was developed within the software to verify the mechanical fit and intended functionality of the individual components before fabrication.



c. **STL File Generation:** Once the digital design was finalized, the 3D models were exported into **STL format**, which is the industry-standard file type required for 3D printing.

Digital Workflow (CAD to G-Code)

- **Modeling:** Solid Edge (High-resolution mesh generation).
- **Exchange Format:** Binary STL with a conversion tolerance of 0.01 mm to 0.1 mm.
- **Slicing Engine:** QIDI Studio (used for generating optimized toolpaths).

d. **Slicing and G-code Generation:** The STL files were imported into the slicing software (QIDI Studio) to convert the design into thin horizontal layers and generate the G-code instructions for the printer.

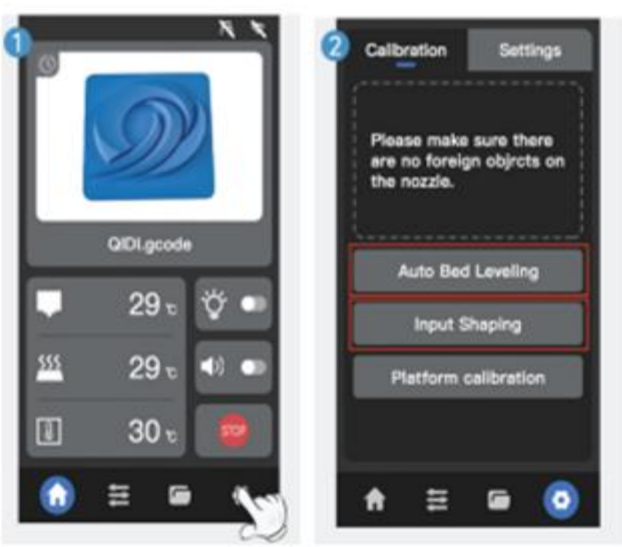
IV. FABRICATION AND ASSEMBLY

Parameter	Value
Material	PLA (Polylactic Acid)
Nozzle Diameter	0.4 mm
Infill Pattern	Grid (20%)
Total Print Time	2 Hours 29 Minutes
Shell Count	3 Walls (suggested for strength)
Semi-Major/Minor Axis	136.5 mm / 84 mm

a. Printer Calibration and Setup

A **QIDI TECH Q1 Pro** FDM printer was utilized for the fabrication. The setup process involved a rigorous three-step calibration:

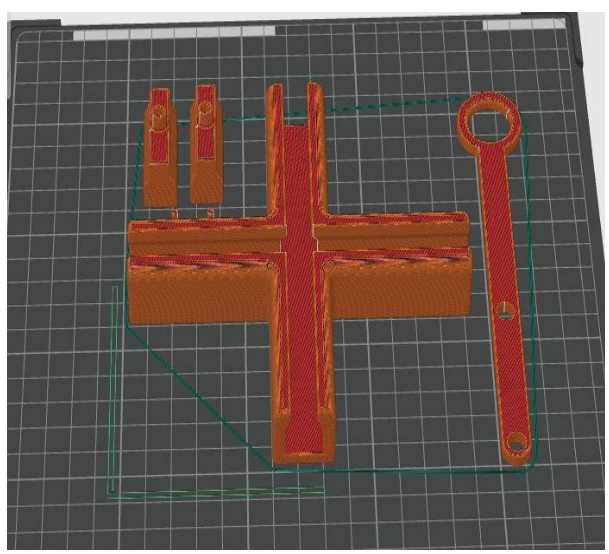
1. **Thermal Prep and Loading:** The nozzle was heated to **210°C** for PLA loading, with the filament end cut at an angle to ensure seamless engagement with the extruder gears.
2. **Automated Bed Leveling:** The system used integrated sensors to probe multiple points on the build plate, automatically compensating for surface irregularities to guarantee consistent first-layer adhesion.
3. **Z-Offset Optimization:** The distance between the nozzle and the bed was fine-tuned to prevent over-compression or poor adhesion. Verification was performed via a **Calibration Cube** and a **First Layer Test**, confirming dimensional accuracy and consistent extrusion before committing to the full build.



b. Calibration and Quality Control

You must prove the accuracy of the printed mechanism:

- **Bed Leveling:** Automated mesh leveling via the QIDI Q1 Pro sensors.
- **Z-Offset Optimization:** Essential for the first-layer adhesion of the trammel base.
- **Verification Protocols:** Use of a **Calibration Cube** for dimensional accuracy and a **Temperature Tower** to minimize stringing and maximize surface finish in the tracks.



IV. RESULTS AND DISCUSSION

The fabrication and testing phase successfully validated the integration of FDM technology with classical kinematic mechanisms.

- **Kinematic Accuracy:** The prototype accurately converted constrained linear sliding motion into a continuous elliptical path. The measured semi-major and semi-minor axes matched the design parameters of **136.5 mm** and **84 mm**, respectively, with minimal deviation.
- **Production Efficiency:** Total fabrication time was optimized to **2 hours and 29 minutes**, utilizing **61.22g** of PLA. The design strategy proved highly efficient, requiring only **0.94g** of support material.
- **Mechanical Integrity:** The structural components, printed at 20% grid infill and 0.2 mm layer height, demonstrated sufficient rigidity to withstand manual operation torque without visible deflection or interlayer failure.

V. CONCLUSIONS

This research confirms that 3D printing is a viable method for producing functional mechanical linkages. The following conclusions were reached:

- **FDM Viability:** Modern desktop 3D printers like the QIDI Q1 Pro can achieve the precision required for slider-crank inversions, provided that a tolerance gap (0.2–0.4 mm) is maintained in the CAD model.
- **Material Performance:** PLA serves as an excellent prototyping medium due to its low thermal shrinkage and high detail retention, making it ideal for educational and motion-study models.
- **Design-for-Manufacturing (DfM):** The use of fillets (3 mm) and optimized part orientation significantly reduced friction and "stair-stepping" artifacts within the trammel channels.

REFERENCES

[1] Notes on the Elliptical Trammel, California Institute of Technology, available at: https://robotics.caltech.edu/wiki/images/4/47/EllipticalTrammel.pdf

[2] Wickramasinghe, S., Do, T., and Tran, P., “FDM-Based 3D Printing of Polymer and Associated Composite: A Review on Mechanical Properties, Defects and Treatments,” *Polymers*, 2020, 12(7), 1529

[3] Double Slider Crank Chain,” IDC Technologies technical reference PDF, available at: https://www.idc-online.com/technical_references/pdfs/mechanical_engineering/Double_Slider_Crank_Chain.pdf

[4] “Oblique Double Slider Ellipse and Straight-line Mechanism,” Cornell Kinematic Models for Design Digital Library

[5] “Drawing Ellipses: Ellipsograph or Trammel of Archimedes,” Matemáticas Visuales

[6] “An Application of Elliptical Trammel For The Purpose of Bottle Shaking,” Zenodo P