



Modeling and Simulation of the Dynamic Behaviour of a Parallelogram Four-Bar Mechanism using ADAMS Software

Akobuche Chikezie*, Otuami Obiga**

***Department of Mechanical/Mechatronics Engineering, Faculty of Engineering, Federal
University Otuoke. P.M.B. 126, Yenagoa, Bayelsa State, Nigeria.**

***Corresponding Author: chikezieaa@fuotuo.ke.edu.ng**

****Department of Mechanical/Mechatronics Engineering, Faculty of Engineering, Federal
University Otuoke. P.M.B. 126, Yenagoa, Bayelsa State, Nigeria.**

ABSTRACT

In this study, automated dynamic analysis of mechanical systems (ADAMS) software is used to describe and simulate the dynamic behavior of a parallelogram four-bar mechanism. An essential part of industrial automation robot arms is this four-bar mechanism. In order to overcome the drawbacks of conventional analytical techniques for dynamic force analysis, the study uses MSC ADAMS software in a computational manner. Key dynamic characteristics, such as joint reaction forces and the input driving torque needed to maintain a constant crank speed, were analyzed using a comprehensive 3D model of the mechanism that was built and simulated. The integrity of the model was validated by the kinematic analysis, which verified the coupler link's pure translational motion. Inertial forces require a disproportionate increase in torque for higher operating speeds, as the dynamic findings showed a key quadratic relationship between crank speed and peak driving torque. The results of this study are crucial for improving the performance, robustness, and efficiency of robotic systems that use this mechanism by refining the design and choosing the right motors and other parts. The study comes to the conclusion that accurate dynamic analysis and well-informed mechanical design decisions require the use of computational tools such as MSC ADAMS.

Keywords: Modelling; Simulation; ADAMS Software; Dynamic Behaviour; Parallelogram Four-Bar Mechanism.

INTRODUCTION

A variety of machines have been created as a result of the numerous ways that humans have evolved over time to lift objects with minimal effort. Traditionally, a machine was defined as a device that could accomplish activities with minimal human intervention (Chikezie, 2025b). According to Chen *et al.* (2022), machines are devices that transform, transfer, and direct forces in order to accomplish a specific objective. Furthermore, the concept of machines has been around since antiquity (Ayodele *et al.*, 2023). Levers, wheels and axles, pulleys, inclined planes, wedges, and screws were the first machines. Later, increasingly complex devices developed, such as automobiles, cranes, and industrial robots with complex systems. A mechanism is the mechanical component of a machine that transmits motion and forces from a power source to an output. The core of the machine is its mechanism (Chikezie, 2025c).

There are several terms related to mechanisms, such as frames, links, joints, and linkage. A mechanism is a system in which inflexible components are joined to create a chain (Cong *et al.*, 2021). A mechanism is a combination of geometrical bodies that make up a machine or a component

of a machine (Fernini, 2022; Wu & Hao, 2020). A mechanism is a combination of rigid or resistant bodies that are created and connected in such a way that they move with specific relative motions with respect to each other. Additionally, a mechanism can be used to transmit, control, or constrain relative movement (Chikezie & Odi-Owei, 2025).

One kind of mechanical linkage is a four-bar linkage, which consists of four rigid bars (links) connected by pivots or joints (Chikezie, 2025). It is the most fundamental and popular connection; it has a range of motion, a mechanical advantage, and creates a closed loop. According to Fong *et al.* (2021), four-bar mechanisms are crucial components of mechanical engineering devices used in anything from automobiles to industrial robotics. According to Guo *et al.* (2024), this system converts rotatory motion into oscillatory motion by adjusting important variables such as time ratio, stroke length, and gearbox angles (Khan *et al.*, 2020). Different combinations of four-bar mechanisms are available, including crank rocker, double crank, parallelogram, and double rocker mechanisms (Kim *et al.*, 2013). Another notable inversion of a four-bar mechanism is the slider crank mechanism, which substitutes a prismatic joint for one of the four revolute joints (Liu & Wang, 2003).

Multiple articulated parallelogram mechanisms are necessary for high-performance parallel robots, such as Delta robots used in high-speed assembly and packaging lines, to control their end-effectors (Chikezie, 2025a; Wang *et al.*, 2020b). These robots connect a stationary base to a moving platform using three or four separate kinematic chains, each of which has a parallelogram linkage (Lu *et al.*, 2024). Accurate servo motors installed on the base drive the cranks in each chain. The platform moves across three dimensions as a result of the rotation of these motors, which power the entire device (Shao *et al.*, 2015; Wang *et al.*, 2020a).

The extraordinary speed and accuracy of the platform are made possible by the integration of the parallelogram linkages (Chikezie & Omah, 2024). The platform's mobility is limited to pure translation in space; it moves without turning and keeps its orientation constant (Singh & Khatait, 2023). So, without having to readjust the gripper, a robot can swoop down, pick up an object, and retract on a straight-line course at amazing speeds. This idea is expanded in flight simulators, where a Stewart platform using hydraulic actuators and comparable parallel kinematics produces realistic pitch, roll, and heave motions for pilot training. The parallelogram components guarantee precise and stiff movement free from undesired rotation (Suh & Choi, 2023; Trochimczuk, 2017).

The focus of this study is to ascertain and assess the forces and torques acting on each link of the mechanism during motion. The parallelogram four-bar mechanism is modeled and simulated to achieve the set objective. Determining the external forces operating along each joint and taking energy into account are additional steps in the dynamic analysis of the parallelogram four-bar mechanism. In this study, the Newton-Euler and Lagrange methods were used to model and simulate the parallelogram four-bar mechanism. For an industrial robot's design, performance improvement, optimization, and structural integrity, this dynamic analysis is crucial.

Using the ADAMS software, this work focuses on modeling and simulating an industrial robot's four-bar mechanism. In the past, analytical techniques were used to conduct dynamic analyses. These techniques were efficient but also susceptible to simplification errors and time commitment. However, in this study, the parallelogram four-bar mechanism was robustly modeled and simulated using the ADAMS software. This computational method greatly cuts down on the amount of time needed for the analysis while also improving accuracy.

2.1 MATHEMATICAL MODELING

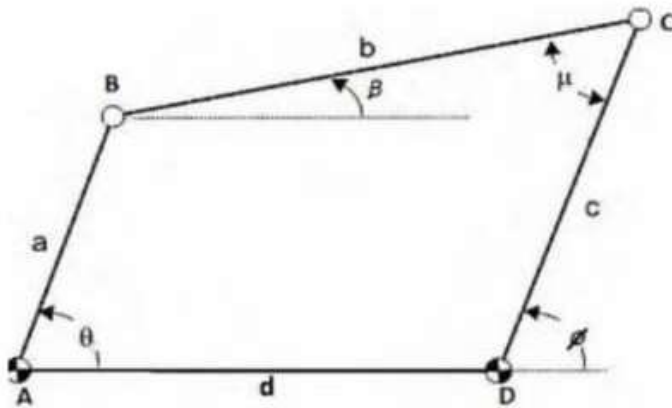


Figure 2.1: The Parallelogram Linkage

Let,

Link AB – a- Crank Link ,BC – b – Coupler Link, CD – c- Rocker Link, AD – d- Fixed link

Θ – Input angle, \emptyset – Output angle

As, O/P angle is a function of I/P angle, we have

$$\emptyset = f(a, b, c, d, \Theta) \quad (2.1)$$

Thus, if values of a, b, c, d and Θ are known, we can find out relationship between Θ and \emptyset .

To determine the relationship between O/P and I/P links, we will use expressions of displacement, velocity and acceleration.

Displacement Analysis:

Position of the O/P link given by \emptyset can be calculated using equation (2.2)

$$\emptyset = 2 \tan^{-1} \left\{ \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \right\} \quad (2.2)$$

Where,

$$A = k - [a * (d - c) * \cos \Theta] - c * d$$

$$B = -2 * a * c * \sin \Theta$$

$$C = K - [a (d + c) \cos \Theta] + c * d \quad 2k = a^2 - b^2 + c^2 + d^2.$$

A relationship between the coupler link position β and I/P link Θ can also be found using eqn (2.3)

$$C * \sin \emptyset = a \sin \Theta + b \sin \beta \quad (2.3)$$

Velocity Analysis:

Let, ω_a , ω_b , ω_c be the angular velocities of the links AB, BC and CD respectively. Value of ω_a is given, value of ω_b and ω_c can be calculated using eqn (2.4.& 2.5)

$$\omega_b = -a * \omega_a * \sin(\emptyset - \Theta) / b * \sin(\Theta - \beta) \quad (2.4)$$

$$W_c = a * \omega_a * \sin(\beta - \theta) / c * \sin(\beta - \theta) \quad (2.5)$$

Acceleration Analysis:

Let $\alpha_a, \alpha_b, \alpha_c$ be angular acceleration of links AB, BC, CD respectively. As per data given in the problem, link AB rotates at uniform angular velocities. In this case, acceleration of input link will be zero i.e. there is no need to calculate it. α_b, α_c can be calculated using

$$\alpha_b = [a * \alpha_a * \sin(\theta - \phi) - \{a * (\omega_a^2) * \cos(\theta - \phi)\} - \{b * (\omega_b^2) * \cos(\theta - \beta) + c * W_c^2\}] / b * \sin(\beta - \theta)$$

$$\alpha_c = [a * \alpha_a * \sin(\beta - \theta) - \{a * (\omega_a^2) * \cos(\beta - \theta)\} - \{b * \omega_b^2 + c * (W_c^2) \cos(\beta - \theta)\}] / c * \sin(\beta - \theta)$$

Matrix Transformation for the Link

Table 2.1: Materials and Geometric Properties of the Mechanism

Parameters	Crank	Coupler	Follower
Length (mm)	1000	1500	1000
Material	Steel	Steel	Steel
Poisson's ratio	0.29	0.29	0.29
Young modulus (GPa)	207	207	207
Density (Kg/m ³)	7801	7801	7801

3 RESULTS AND DISCUSSION

The results of the parallelogram four-bar mechanism's computer modeling and multi-body dynamic simulation are presented in details in this section. The dynamic reaction of the system at a constant crank angular velocity is the main focus of the analysis, which is carried out in the MSC Adams environment. Plots and animations produced by the Adams/Post Processor module are used to methodically display the results. Important performance metrics are analyzed and evaluated, such as the kinetic and potential energy profiles of the links, the necessary input torque at the crank, and the joint reaction forces at each revolute joint. These findings demonstrate the crucial inertial factors influencing the mechanism's design and validate the theoretical underpinnings of its functioning. The crank speed used for the first analysis was 360 degrees per second, or 60 RPM.

3.1: The CAD Model of the Mechanism

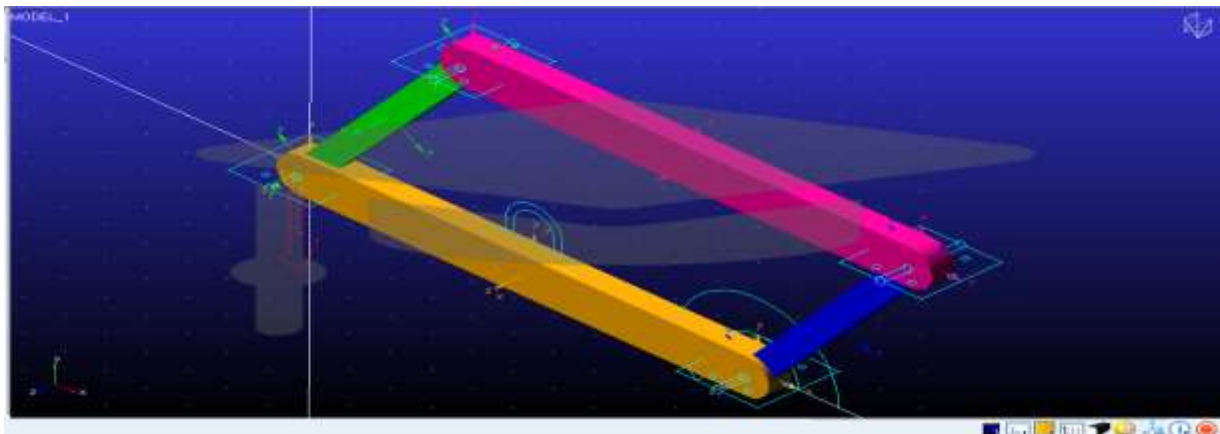


Figure 3.1 (a): The CAD Model of the Mechanism

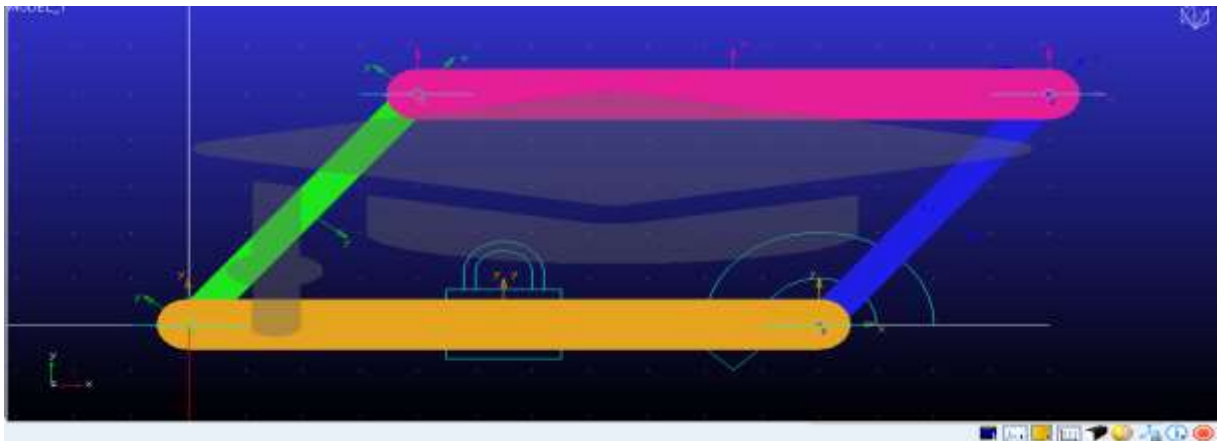


Figure 3.1 (a): The 3D Model of the Mechanism

3.2 Dynamic Analysis of the Mechanism

3.2.1 Joint Reaction Force Analysis

These include the joint reaction forces of all the joints of the mechanism.

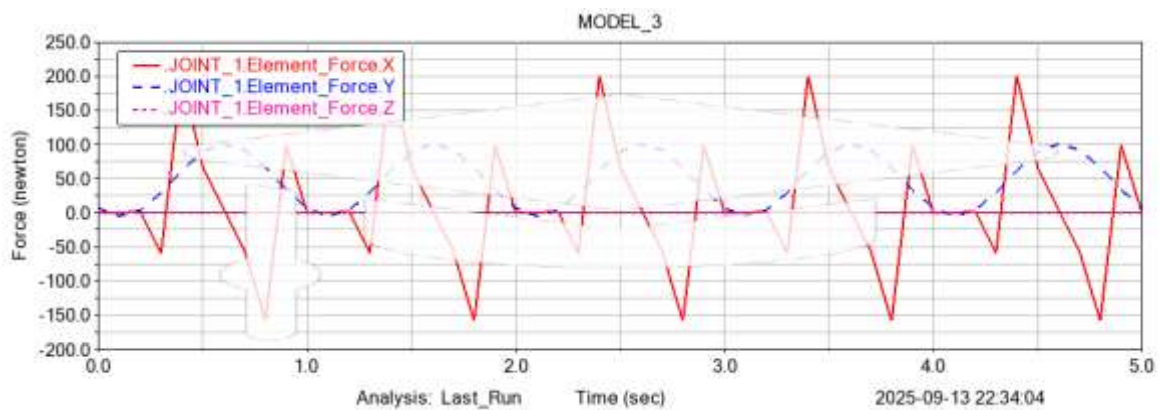


Figure 3.2: Joint 1

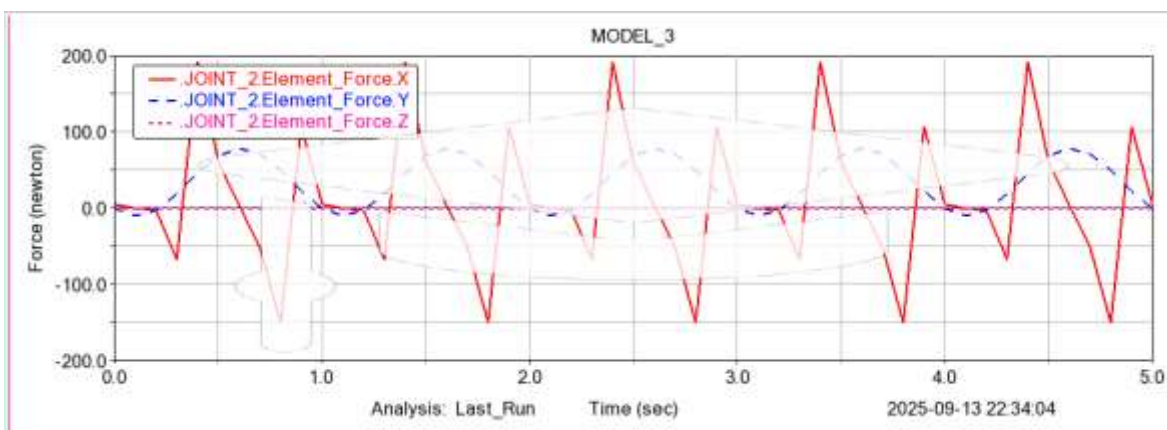


Figure 3.3: Joint 2

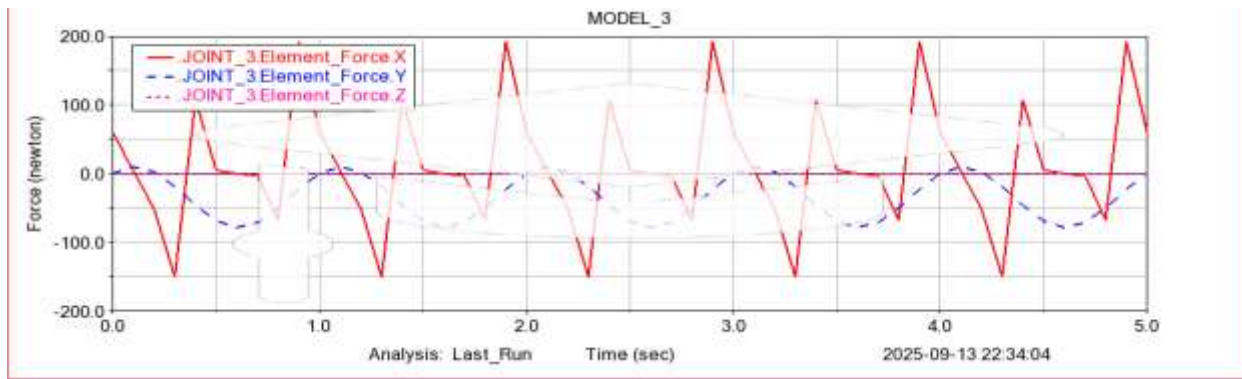


Figure 3.4: Joint 3

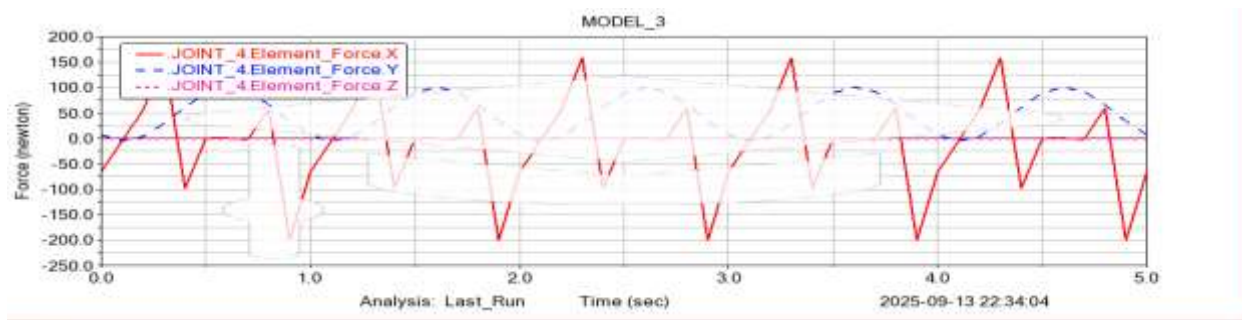


Figure 3.5: Joint 4

Figures 3.2 to 3.5 illustrate how the highly dynamic element-forces X (F_x) of joints (1-4) exhibit peaks and dips. Significant inertia or load transfer through this axis is suggested by the peaks, which are $\pm 200\text{N}$. This shows varying horizontal force on the joints above as a result of the input motion. In contrast, the Element-forces Y (F_y) hover around $\pm 50\text{N}$ and have smaller fluctuations. Perhaps as a result of symmetrical design or restrictions on vertical movement, vertical forces are more stable.

3.2.2 Driving Torque Analysis

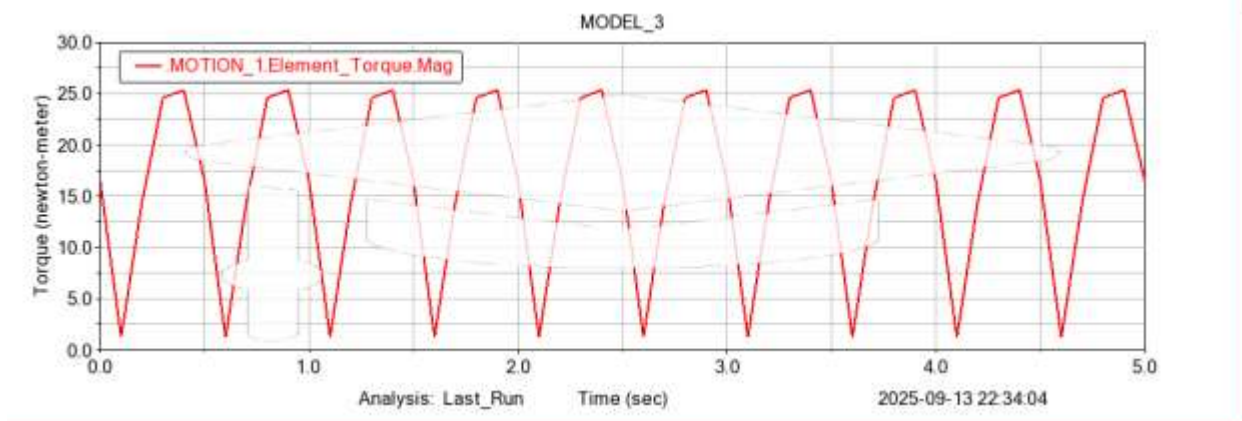


Figure 3.6: Torque Analysis

In order to maintain the precisely defined constant rotational speed (360 degrees per second) over the entire cycle, Figure 3.6 illustrates the instantaneous torque that must be applied to the actuator (revolute joint) connected to the crank. The torque vector's absolute value, which is always positive, is represented by the magnitude type plot. This is helpful in figuring out the motor's maximum load. The torque vs. time plot is an essential design tool, not just a result.

The maximum value on this graph (25 Nm) must be exceeded by the motor's peak torque rating. The motor will "stall" at the horizontal locations if it is unable to provide this torque. Figure 3.6 displays

the system's varying power requirements. Energy consumption and regeneration are shown by the areas under the positive and negative torque curves, respectively. The outcome demonstrates that dynamic loads are substantial and extremely changeable, even for a basic mechanism operating at a steady pace. It highlights the importance of dynamic simulation in programs like Adams, as static analysis would entirely overlook these impacts.

3.3 Comparison of the Driving Torque with varying Crank Speed

Crank speed(deg/s)	Crank speed (RPM)	Peak driving torque (Nm)
300	50	17
310	51.67	19
320	53.33	20
330	55	21
340	56.67	22
350	58.33	24
360	60	25

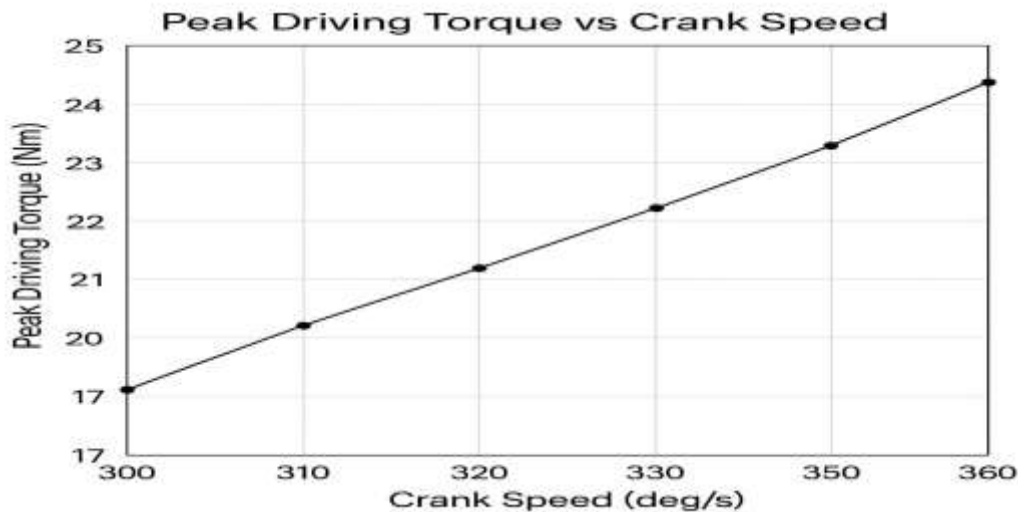


Figure 3.6: Peak Driving Torque vs Crank Speed

Just a 20% increase in speed from 300 deg/s to 360 deg/s results in a 44% increase in torque from 17 Nm to 25 Nm, demonstrating a critical quadratic relationship between crank speed and peak driving torque, where the torque requirement scales with the square of the speed. This tendency is caused by the predominance of inertial forces, particularly centripetal acceleration, which demands a much higher input torque in order to keep the masses of the mechanism moving steadily at higher velocities. This highlights a fundamental performance limitation where even modest speed increases require disproportionately more powerful and expensive drive components to overcome the rapidly increasing inertial demands. As a result, this has significant implications for system design, as motor selection must take these dynamic peak loads into account rather than static forces.

CONCLUSION

In this study, a parallelogram four-bar mechanism was successfully modeled, simulated, and dynamically analyzed using MSC Adams. By proving the coupler link's pure translational motion—a basic property supported by its consistent angular displacement and predictable route trajectories—the kinematic analysis definitively established the model's integrity. A crucial precondition for the ensuing dynamic analysis was establishing this proper kinematic behavior.

Important information about the system's performance in the real world was revealed by the dynamic analysis. Important joint reaction forces and the oscillating input torque needed to keep the crank speed steady were measured by the simulation; this information is crucial for choosing motors, bearings, and guaranteeing structural stability. Adams' worth as a formidable tool for forecasting intricate dynamic behavior and guiding wise design choices was further highlighted by the observed energy exchange between kinetic and potential forms, which resulted in a conserved total energy and confirmed the simulation's physical accuracy.

REFERENCES

- Ayodele, K. P., Omolayo, I., Komolafe, E. A., Jubril, A. M., Obreba, P., Ogunmodede, A., Olateju, ., Ajayi, O., Olaogun, M. O., & Komolafe, M. A. (2023). A Technique for End-Effector Force Estimation in Parallelogram Arm Robot using Link-Integrated Load Cells. *FUOYE Journal of Engineering and Technology*, 8(2). <https://doi.org/10.46792/fuoyejet.v8i2.1035>
- Chen, R., Wang, W., Wu, K., Zheng, G., Xu, X., Wang, H., & Luo, J. (2022). Design and optimization of a novel compliant planar parallelogram mechanism utilizing initially curved beams. *Mechanism and Machine Theory*, 179, 105092 <https://doi.org/10.1016/j.mechmachtheory.2022.105092>
- Chikezie, A. (2025a). Attenuation of the Centrifugal Governor's Nonlinear Behaviour: A Novel Mathematical Approach. *International Journal of Machine Design and Technology* Vol. 1, Issue 2 (July – December, 2025) pp: (22-28)
- Chikezie, A. (2025b). Acceleration analysis of a slider crank mechanism: A novel mathematical approach,” *Res. Rev. J. Mech. Mach.*, vol. 7, no. 1, pp. 13–20, 2025. Doi: <https://doi.org/10.5281/zenodo.14760372>
- Chikezie, A. (2025c). Mathematical modelling of displacement of a slider-crank mechanism for a pick and place robot arm: An algorithmic approach,” *Res. Dev. Mach. Des.*, vol. 8, no. 1, pp. 9–17, 2025. Doi: <https://doi.org/10.5281/zenodo.14832647>
- Chikezie, A. (2025). Velocity analysis of a slider crank mechanism for delta robot arm manipulation: A computational approach,” *Br. J. Multidiscip. Adv. Stud. Eng. Technol.*, vol. 6, no. 1, pp. 11–21, 2025. Doi: <https://doi.org/10.37745/BJMAS.2022.04220>
- Chikezie, A & Odi-Owei, S. (2025). Kinematic analysis of a slider-crank mechanism for delta robot arm manipulation: A computational approach,” *Res. Rev. J. Mech. Mach.*, vol. 7, no. 1, pp. 33– 46, 2025. Doi: <https://doi.org/10.5281/zenodo.15064132>
- Chikezie, A & Omah, I. (2024). Development of contact models for wear predictions in mechanical and mechatronic systems,” *Recent Trends Automob. Eng.*, vol. 7, no. 3, pp. 43–50.
- Cong, V., Duy, D., & Phuong, L. (2021). Design and Fabrication of 3-DOF Robot Arm Using Parallelogram Mechanisms. *International Journal of Emerging Trends in Engineering Research*, 9(9), 1224–1229. <https://doi.org/10.30534/ijeter/2021/03992021>
- Fernini, N. B. (2022). Mathematical modelling and simulation investigation of the dynamic behaviour of a compliant 2-R robot by using N-E method Via Matlab/Simulink. *International Journal of Frontiers in Engineering and Technology Research*, 3(1), 010–019. <https://doi.org/10.53294/ijfetr.2022.3.1.0048>
- Fong, S., Leong, P. K., Min, H. N., Leong, P. C., & Hu, Z. G. (2021). Modeling and analysing of spring-loaded double parallelogram mechanism using moment balance. *Journal of Physics Conference Series*, 1777(1), 012063. <https://doi.org/10.1088/1742-6596/1777/1/012063>
- Guo, Z., Ju, H., Lu, C., & Wang, K. (2024). Dynamic modeling and improved nonlinear model predictive control of a Free-Floating Dual-Arm space robot. *Applied Sciences*, 14(8), 3333. <https://doi.org/10.3390/app14083333>
- Khan, S., Jamal, A., Ali, S., Horoub, M. M., Albalasie, A., & Ali, S. (2020). Dynamic modeling and analysis of a four-bar mechanism for automobile applications. *2019 International Conference on Electrical, Communication, and Computer Engineering (ICECCE)*, 1–6. <https://doi.org/10.1109/icecce49384.2020.9179221>
- Kim, J., Cho, S., Lee, C., Han, J., & Hwang, H. (2013). Kinematic and dynamic analyses of human arm motion. *Journal of Biosystems Engineering*, 38(2), 138–148. <https://doi.org/10.5307/jbe.2013.38.2.138>

- Liu, X., & Wang, J. (2003). Some new parallel mechanisms containing the Planar Four-Bar parallelogram. *The International Journal of Robotics Research*, 22(9), 717–732. <https://doi.org/10.1177/02783649030229003>
- Lu, H., Yang, Z., Zhu, D., Deng, F., & Guo, S. (2024). Dynamics modeling and parameter identification for a Coupled-Drive Dual-Arm nursing robot. *Chinese Journal of Mechanical Engineering*, 37(1). <https://doi.org/10.1186/s10033-024-01063-z>
- Shao, Z., Tang, X., & Wang, L. (2015). Dynamics Verification Experiment of the Stewart Parallel Manipulator. *International Journal of Advanced Robotic Systems*, 12(10). <https://doi.org/10.5772/61541>
- Singh, A., & Khatait, J. P. (2023). Sensitivity analysis of a double-parallelogram based RCM mechanism used for MIS robots. *Proceedings of the Institution of Mechanical Engineers Part C Journal of Mechanical Engineering Science*, 237(20), 4813–4827. <https://doi.org/10.1177/09544062231153818>
- Suh, J., & Choi, W. (2023). Design and verification of parallelogram mechanism with geared unit rolling joints for reliable wiring. *IEEE Robotics and Automation Letters*, 8(6), 3756–3763. <https://doi.org/10.1109/lra.2023.3264716>
- Trochimczuk, R. (2017). Analysis of Parallelogram Mechanism used to Preserve Remote Center of Motion for Surgical Telemanipulator. *International Journal of Applied Mechanics and Engineering*, 22(1), 229–240. <https://doi.org/10.1515/ijame-2017-0013>
- Wang, H., Song, M., Li, M., Yang, R., & Jiang, Z. (2020a). Dynamics analysis of a novel two-translation parallel mechanism. *Vibroengineering PROCEDIA*, 33, 193–198. <https://doi.org/10.21595/vp.2020.21686>
- Wang, J., Zhou, L., Chen, L., & Li, Y. (2020b). Dynamic modeling and cooperative process simulation in cooperative Dual-Arm robot based on ADAMS. *Journal of Physics Conference Series*, 1621(1), 012041. <https://doi.org/10.1088/1742-6596/1621/1/012041>
- Wu, K., & Hao, G. (2020). Design and nonlinear modeling of a novel planar compliant parallelogram mechanism with general tensural-compressural beams. *Mechanism and Machine Theory*, 152, 103950. <https://doi.org/10.1016/j.mechmachtheory.2020.103950>