Improving Kinematic Performance of Geneva Mechanisms in Robotic and Automated Systems: A Comparative Study on Slot Count Using MATLAB Simulations

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ABSTRACT

Geneva mechanisms are widely used in robotic and automated systems to produce controlled intermittent motion. However, their dynamic behaviour—especially changes in acceleration and velocity—can significantly affect mechanical wear, vibration, and system accuracy. This study presents a comparative analysis of Geneva mechanisms with different slot counts (N = 4, 6, and 8) to understand how slot number influences motion smoothness and dynamic performance. Using MATLAB-based simulations, angular displacement, velocity, and acceleration profiles were generated while maintaining constant geometric and input parameters. Results indicate that increasing the number of slots reduces peak angular acceleration and velocity fluctuation, improving overall motion continuity. This study presents a comparative kinematic analysis of Geneva mechanisms with slot counts N = 4, 6, and 8 using MATLAB simulation. A smoothness index is proposed to quantitatively compare motion continuity and dynamic response. This contributes design-oriented insights for robotics and CNC tool changers. The present work is simulation-based and provides a foundation for future experimental validation.

Keywords: Geneva Mechanism; Kinematic Optimisation; Intermittent Motion; Robotics Automation; MATLAB Simulation; Slot Count Effect.

Nomenclature:

θ = Angular displacement (^{0})

ω = Angular velocity (^{0}/s)

α = Angular Acceleration ($^0/s^2$)

Rw = Driven wheel radius (mm)

Rp = Driver pin radius (mm)

C = Centre distance between the driver and driven wheel (mm)

Φ = Half-angle of indexing (^{0})

ω = Constant angular velocity of the driver (rad/s)

Rlock = Locking radius (mm)

N = Number of slots

v = Linear velocity of the pin = Rp × ω,

t = Time elapsed during the indexing phase (sec)

INTRODUCTION

A popular indexing method that produces intermittent motion with high positional accuracy from continuous rotation is the Geneva mechanism [1]. A driven wheel with uniformly spaced radial slots and a driving wheel with a pin are the components of a conventional Geneva mechanism. The pin occasionally makes contact with a slot on the driven wheel as the driving wheel revolves, producing a noticeable angular progress. A locking mechanism holds the driven wheel in place between these engagements, reducing backlash and guaranteeing position stability. Nevertheless, the traditional Geneva mechanism, especially those with few slots, frequently shows serious dynamic problems, such as high impact forces and vibrations during engagement and disengagement, which can impair longevity and performance [2]. Traditionally, Geneva mechanisms have been used in timing applications such as clocks, watches, and film projectors. The research explores a novel internal combustion engine design using the Geneva mechanism[3]. Examining several SMA actuator topologies, the study emphasizes how mechanical design affects thermal performance, displacement, and efficiency. In robots and flexible systems, these insights are crucial for optimizing small mechanisms such as the Geneva drive [4] This paper presents a polynomial-based design for changing input speed that minimizes peak acceleration and angular jerks in Geneva mechanisms. For efficient performance enhancement, it uses optimization based on teaching-learning, and its results are comparable to those of current length-adjustable link techniques [5]. A spiral Geneva mechanism is used in this study's vertical pneumatic fertilization system to provide accurate and consistent fertilizer flow. According to simulation and experimentation, opening and rotating speed have a significant impact on discharge accuracy, providing important information for fine-tuning Geneva-based mechanisms in precision applications [6]. The study uses ANSYS APDL to model contact behaviour under various material qualities in order to investigate a Geneva mechanism in an autonomous stamping machine. It draws attention to how material choice has a big impact on contact and stress performance, which helps with design optimization for effectiveness and less human labour [7]. For curved slotted Geneva mechanisms, this paper suggests an indexing motion based on Hermite interpolating polynomials to minimize peak angular acceleration and get rid of infinite jerks. Its kinematic performance can be improved by up to 33.4%, surpassing that of conventional motion profiles [8]. This study highlights the simplicity, dependability, and automation appropriateness of a Geneva mechanism by showcasing its efficient application in CNC tool changers. Despite its efficiency, scaling up presents challenges due to tool capacity and design complexity [9]. Modern engineering is still interested in the Geneva mechanism, which is renowned for transforming rotary motion into accurate intermittent motion. In this work, a synthesis method backed by computer-aided dynamic and kinematic analysis is presented. To calculate component size and motion parameters, a specialized program was created, allowing for precise 3D modelling of the mechanism[10]. The flexible impulse of the Geneva wheel and its unsuitability for high-speed applications are highlighted in this study's comparison of four intermittent motion devices.

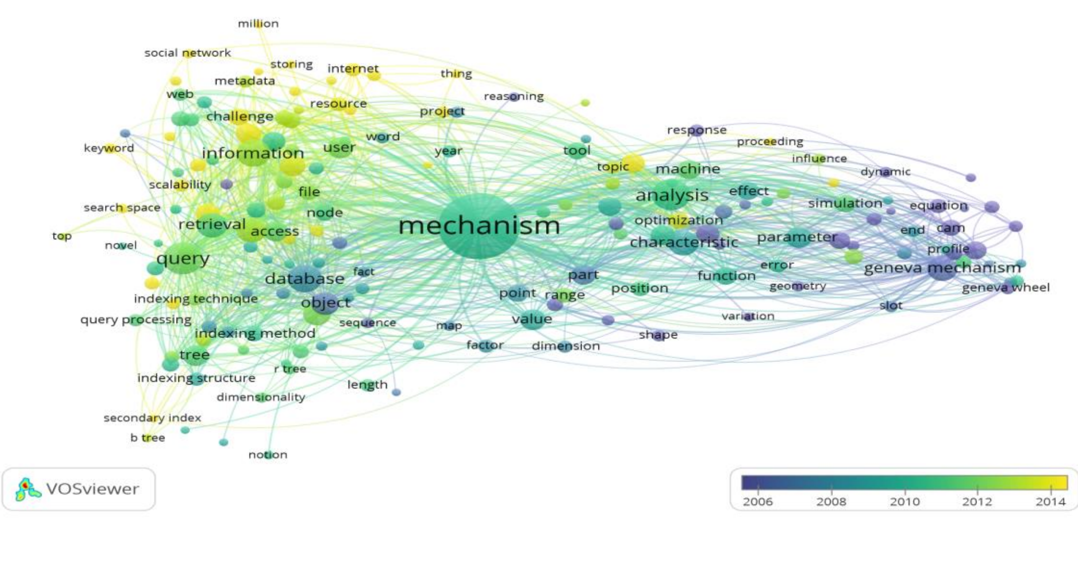

Figure 1. Keyword-wise network visualization map

Motion analysis and parametric design were combined with ease using NX8.5. The unified data strategy improves visualization accuracy and design efficiency [11]. This work uses ABAQUS and FE-SAFE to assess the fatigue life and stress distribution of an external Geneva mechanism under three loading scenarios. The pin contacts at the bottom of the wheel slot, which exhibit the highest stress, according to the results. Similar tension results from increasing crank speed or torque. The fatigue life of the pin is longer than that of the Geneva wheel [12]. This paper proposes a synthesis approach based on a desired motion law for groove-cam Geneva mechanisms with long dwell times. Additionally, the cam curvature radius and pressure angle are controlled by the design. This design avoids soft impacts, double locking, and permits smoother transitions than the classic Geneva designs. This study provides an overview of the Maltese cross (Geneva) mechanism, which is frequently employed in robotics, automation, and force transmission systems. It investigates the geometry, kinematics, and dynamic forces of a fourth-class upper coupler configuration. Its position alongside gears and its importance in conveying peak moments are highlighted in the analysis [13]. A Geneva mechanism tool changer prototype was created for CNC machines. Laser cutting and 3D printing were used to construct the components. Although the design is dependable and economical, its scalability is still a drawback [14]. Designing Geneva mechanisms with curved slots is done methodically using envelope theory. The study examines double-point and undercutting issues in the curve profile. To avoid these issues, design charts are created, and the suggested approach is validated by a physical mock-up [15]. In order to optimize weight, manufacturing industries frequently use sheet metal shaping. In this paper, a Geneva mechanism is used to improve intermittent operations in place of the conventional crank slotter. A slotted Geneva wheel's kinematics are determined using DH notations and curve theory analysis. Contact stresses between the wheel grooves and the pin are assessed using finite element analysis [16].It is used in CNC machines and paper-cutting setups [17]. Table 1 indicates the Practical implications: increasing slot count reduces per-step angular increment but shortens dwell and changes peak magnitudes;

Table 1. Slot count effects and comparisons

Slot configuration	Observed kinematic effect	Key quantitative result
3 slots (external/internal)	Longer motion interval per step → larger angular velocity/acceleration peaks	Comparative study used 3, 6, 9 slots and shows different peak behaviours across configurations [18]
4 slots	Standard teaching/demo case; baseline kinematics analyzed for education and design decision support	Kinematic analysis and design guidance for a 4-slot teaching aid are provided [21]
6 slots	More frequent, smaller steps → reduced peak angular velocity/acceleration in some link combinations	Swadi reports reduced maxima for certain crank-rocker couplings compared with other counts [18]
9 slots	Even smaller steps per index but shorter dwell; can change dynamic envelope and increase certain accelerations depending on geometry	Included in comparative study of 3, 6, 9 slots [18]
3–15 slots (groove-cam synthesis)	The operating time coefficient and dwell augmentation vary systematically with slot count; a wide achievable range of operating time coefficients.	Analyses for cycloidal motion law show an achievable operating time coefficient range of 0.053–0.765 across 3–15 slots and dwell coefficient variations [19]
Curved/grooved slots	Reduces impact at entry/exit, lowers angular acceleration and vibration, enables specified motion laws and soft transitions	Curved-slot designs and groove-cam synthesis produce fewer soft impacts and reduced accelerations (up to 3× reduction observed experimentally) [20] [19]

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groove or curved slots permit tailoring the motion law and reducing soft impacts while synthesis constraints (pressure angle, cam curvature) must be respected [18] [19] [20]. A modified Geneva mechanism that reduces motion discontinuities by employing an epitrochoidal path rather than the conventional circular pin path is examined in this work. In order to achieve smoother velocity, acceleration, and jerk profiles, a gear train creates this path. In order to reduce excessive jerk, the study applies a non-circular gear pair to further improve motion and compares classical and modified methods[22]. A keyword-wise network visualization (2006–2014) highlights “mechanism" as the central research focus, showing strong interlinkages with terms like "analysis," "parameter," and "simulation." Notably, "Geneva mechanism" clusters with keywords such as "geometry," "cam," and "dynamic," indicating growing scholarly attention toward kinematic modelling and optimization in precision motion systems in Figure 1. The Geneva mechanism, though classical in origin, plays a critical role in modern robotic and autonomous systems where precise intermittent motion is essential—such as robotic assembly lines, CNC-based tool changers, or packaging automation. Although the classical mechanical design literature has extensively studied Geneva mechanisms, few comparative studies exist across different slot counts (N). Static geometric design or single-slot arrangements are the main subjects of current research. This study systematically compares Geneva mechanisms with varying slot counts (N = 4, 6, and 8), providing quantitative analysis of kinematic performance metrics to support design optimization. By introducing a normalized smoothness index and quantifying reductions in acceleration peaks and velocity fluctuations, this study provides actionable insights into the trade-offs between rapid indexing and smooth motion. While prior studies optimize curved slots, dwell design, and stress analysis, none provide a quantified comparison of slot count effect on smoothness and mechanical stress. This gap is addressed in the present work.

METHODOLOGY

This section presents the kinematic analysis and geometric modelling approach of the Geneva mechanism. The goal of the work is to derive time-parameterized equations for the driven wheel's angular displacement, velocity, and acceleration given a constant angular input. MATLAB 2025b is used for the analysis.

Geometric Assumptions and Parameters

The Geneva mechanism under consideration has 4 slots (N = 4) on the driven wheel and is a classical external-drive type. These are the primary geometric parameters, Rw = 50 mm, Rp = 5 mm, C=70.71 mm, Slot indexing angle: 360°/N = 90°, φ= 45°, ω= 10 rad/s (constant), R_{lock} ≈ = 61.24 mm**.** The indexing angles per slot correspond to 360°/N. For N = 4 → 90°, N = 6 → 60°, N = 8 → 45°.

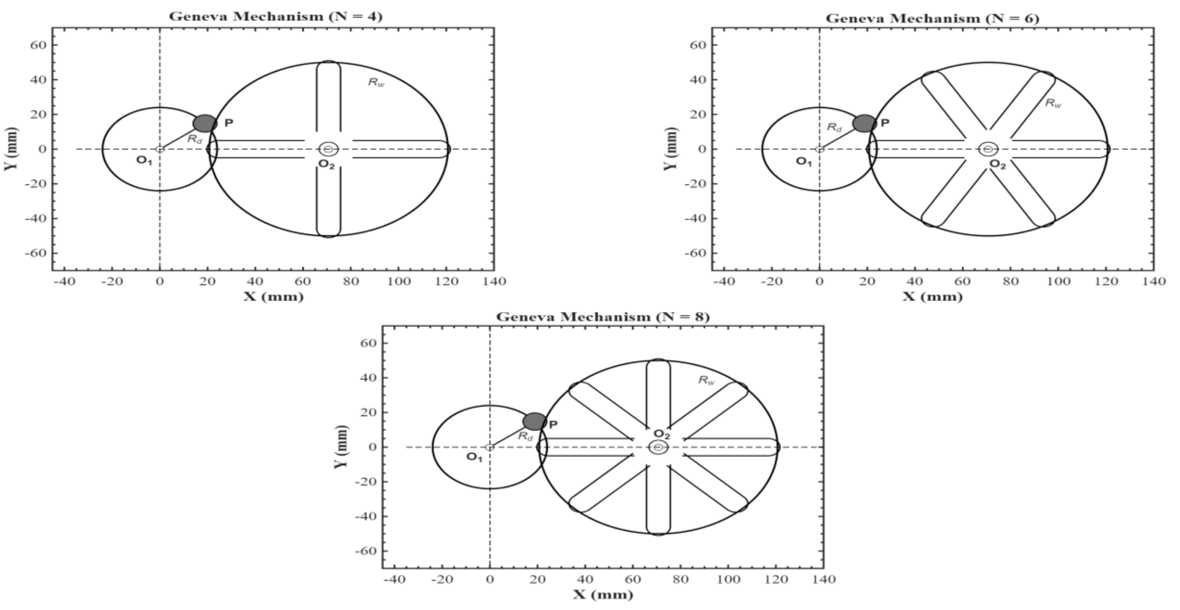

Figure 2. Comparative Geometric Models of Geneva Mechanisms (N=4,6,8)

The analysis assumes planar motion, idealized rigid bodies, negligible backlash, and minimal friction—standard conditions for kinematic studies of Geneva mechanisms. Figure 2 Geometric configuration of Geneva mechanisms with different slot numbers: (a) four-slot (N = 4), (b) six-slot (N = 6), and (c) eight-slot (N = 8). The figure illustrates the driving wheel radius Rd, the driven wheel radius Rw, the centres of rotation O1 and O2, and the engagement point P between the driving pin and the Geneva slots. Variation in the slot count influences the indexing angle, motion transfer characteristics, and kinematic performance of the mechanism.

Kinematic Modelling and Equations

Angular Displacement of the Driven Wheel

The driving pin travels in a circular arc when engaged, imparting motion to the Geneva wheel through one of its radial slots. Given the driver rotation angle (ωt), the driven wheel's angular displacement, θ(t), may be found using the following formula:

$$\theta(t) = \tan^{-1}\left(\frac{R_p \sin(\omega t)}{C - R_p \cos(\omega t)}\right) \tag{1.1}$$

Based on the planar vector geometry of the Geneva mechanism, this expression accounts for the driven wheel's instantaneous angular position as a function of time and relative geometry.

Angular Velocity and Acceleration

The angular velocity and acceleration of the driven wheel are obtained by numerically differentiating the displacement function:

$$\omega_2(t) = \frac{d\theta}{dt}; \alpha_2(t) = \frac{d^2\theta}{dt^2} \tag{1.2}$$

The gradient () function in MATLAB is used to compute these derivatives using finite-difference approximations. Smooth and precise derivative estimation is ensured by using a high-resolution time vector.

Time-Parameterized Driver Rotation

The time needed for a full indexing motion, assuming the driver's angular velocity (ω = 10 rad/s) remains constant, is:

$$t_{index} = \frac{\Delta\theta_{driver}}{\omega} = \frac{\pi}{2\omega} \tag{1.3}$$

A consistent, small-increment time vector from t=0 to t= t_{index} It is possible to simulate θ(t), ω2(t), and α2(t) throughout the whole indexing phase by using Δt. Using the same driver input conditions, this modelling approach compares motion smoothness, peak accelerations, and indexing times to promote design optimisation and enable dynamic study of various slot configurations (N = 4, 6, 8).

Hand-Derived Kinematic Equations

Assumptions and Approach

The Geneva mechanism has N = 4 slots, which means that during each indexing phase, the driven wheel rotates 90° (π/2 radians). The angular velocity of the driver's rotation is constant at ω = 10 rad/s. The driver pin follows a circular arc of radius Rp. The angular position of the driven wheel is determined by the relative displacement of the driver pin and the driven wheel centre. The For the hand derivation, a simplified geometric model is employed, and MATLAB is utilized to develop it numerically.

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Angular Position θ(t)

Applying the law of cosines to the triangle made up of the driver pin, driver wheel centre, and driven wheel centre yields the angular displacement θ(t) of the driven wheel.

The driver pin's relative displacement from its starting location can thus be represented in terms of time as follows:

$$d(t) = \sqrt{R^2{}_p + (v^2 t^2)} \quad (1.4)$$

Finding the angle θ(t) between the vectors linking the driver and driven wheel centres using the law of cosines:

$$\theta(t) = arccos(\frac{C^2 + R_w{}^2 - [R^2{}_p + (v^2 t^2)]}{2CR_w}) \quad (1.5)$$

Throughout the active indexing phase, this equation calculates the Geneva wheel's instantaneous angular position. Its foundation lies in geometry and is predicated on the idealized, seamless transfer of motion.

Angular Velocity ω_2(t)

The driven wheel's angular velocity is equal to the angular position's first time derivative:

$$\omega_2(t) = \frac{d\theta(t)}{dt} \quad (1.6)$$

While this derivative is analytically possible, the nonlinear structure of the θ(t) function makes it complex to differentiate by hand. Hence, in practice, this derivative is calculated numerically using MATLAB’s gradient () function:

$$\omega_2(t) \approx \frac{\Delta\theta}{\Delta t} \quad (1.7)$$

Angular Acceleration α_2(t)

Similarly, angular acceleration is the second derivative of θ(t):

$$\alpha_2(t) = \frac{d^2\theta(t)}{d^2 t} \quad (1.8)$$

Which is computed numerically as:

$$\alpha^2(t) \approx \frac{\Delta\omega_2}{\Delta t} \quad (1.9)$$

This method allows for accurate estimation of dynamic characteristics like peak acceleration, which is critical in evaluating mechanical stress and vibration in high-speed Geneva mechanisms.

MATLAB Simulation

All of the fixed geometry and simulation parameters utilised throughout the analysis are shown in Table 2. It

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Table 2. Input Parameters Used in Simulation

Parameter	**Symbol**	**Value**	**Units**
Driver Pin Radius	Rp	5	mm
Driven Wheel Radius	Rw	50	mm
Driver Angular Velocity	ω	10	rad/s
Slot Counts Tested	N	4, 6, 8	–
Time Step for Simulation	Δt	0.001	s
Index Angle per Slot	360∘ /N	90°, 60°, 45°	degrees

specifies key parameters such as the constant driver angular velocity (ω=10 rad/s), driven wheel radius (Rw=50mm), and driver pin radius (Rp=5mm). Additionally, it provides the indexing angles for each slot configuration (900, 600, and 450 for N=4, 6, and 8, respectively) and the time step utilised in the MATLAB simulation (Δt=0.001s). Numerical differentiation was performed using MATLAB gradient() with time step Δt = 0.001 s. The basic configuration for reproducible and reliable simulation results is given by this table.

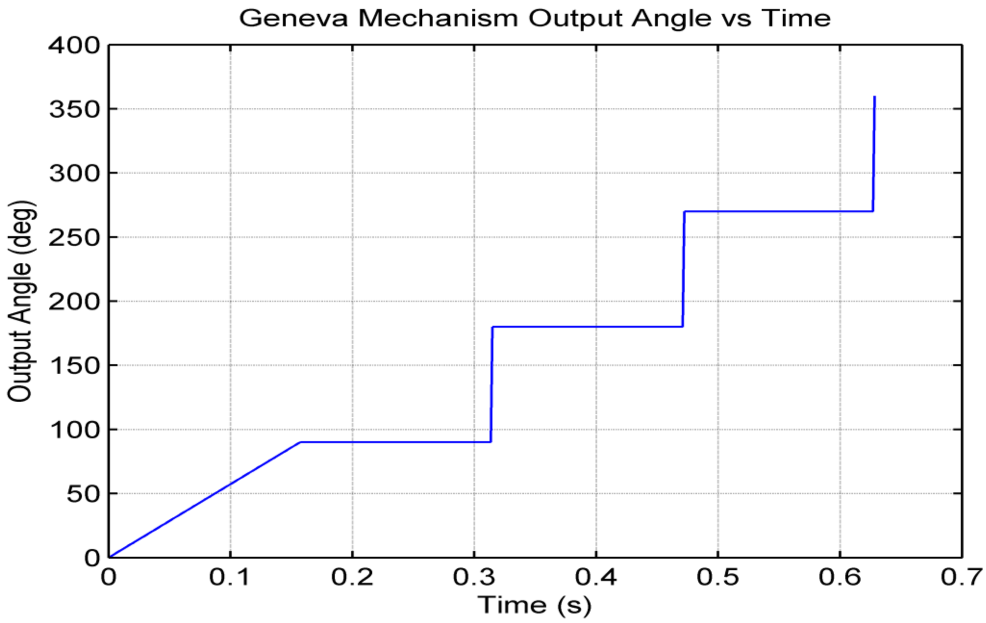

Figure 3. Angular displacement of driven wheel showing indexing and dwell periods

Performance Metrics

Three key performance indicators were used to quantify kinematic smoothness and dynamic performance:

- Peak Angular Acceleration ($|\alpha_{max}|$)
- Velocity Fluctuation (Δω)
- Smoothness Index (S)

$$S = 1 - \frac{|\alpha_{\max}|}{\alpha_{ref}} \quad (1.10)$$

with α_{ref} corresponding to the peak deceleration for N = 4,6,8. These metrics facilitate objective evaluation of trade-offs between indexing speed and motion smoothness.

RESULTS AND DISCUSSION

Kinematic Response: Angular Position, Velocity, and Acceleration

MATLAB 2025b was used to develop a simulation script (geneva_motion.m) to compute angular displacement, velocity, and acceleration. The following input parameters are adopted in the simulation: Rp = 5 mm, Rw = 50 mm, C = 70.71 mm.The Geneva mechanism's output angle is plotted against time in Figure 3. The mechanism's intermittent motion feature—in which the output spins during engagement and stays motionless during dwell periods—is aptly demonstrated by the stepped profile. Each abrupt rise represents a single indexing event, and dwell time is represented by flat areas. The steps' uniform height confirms consistent angle increments, and the regular time of driver engagement is reflected in the distance between them.[23]. This pattern validates the proper Geneva indexing behaviour.

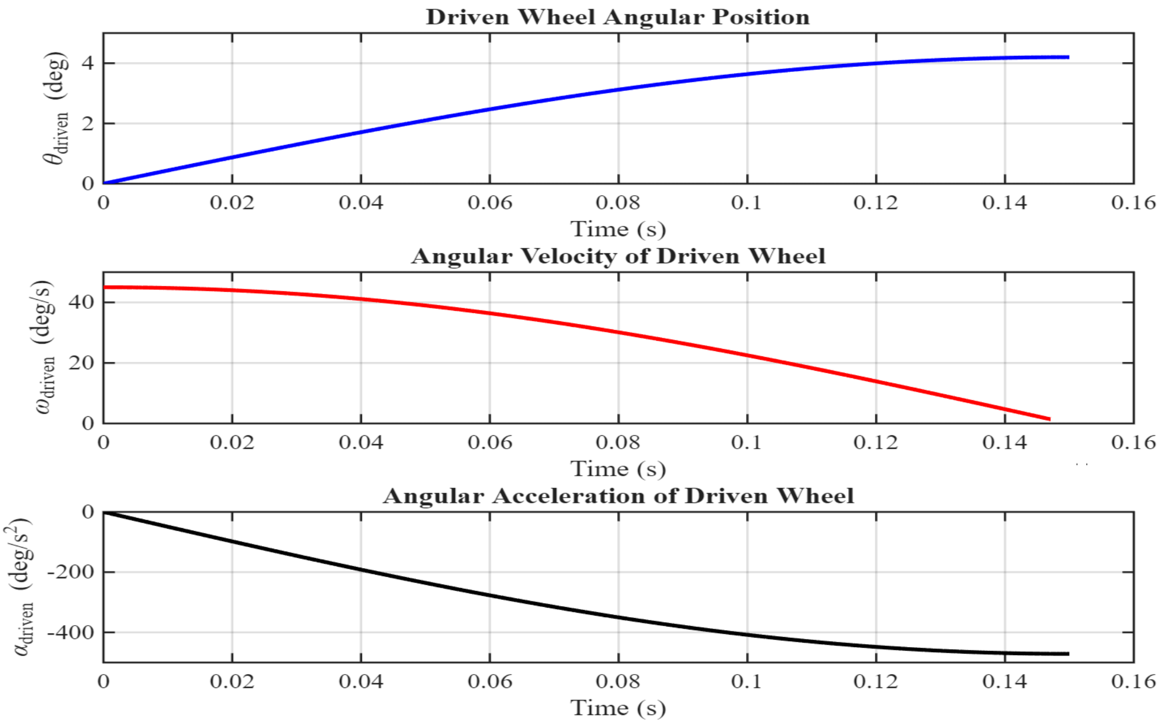

Figure 4. Time history of θ, ω, and α during one indexing cycle (N = 4)

Using the input parameters Rp=5 mm, Rw=50 mm, and centre distance C=70.71 mm, Figure 4 depicts the kinematic reaction of a driven wheel of a Geneva mechanism during the course of one indexing cycle. The top plot shows the angular position $\theta_{driven}(t)$, which increases non-linearly over time. The growth is initially slow (0–0.03 s), corresponding to the instant after the driver pin enters the slot but before the lever arm starts to work. Because limited torque is transmitted at shallow engagement, there is a "lag" phase. The mid-stroke period (0.03–0.12 s) is when the curve steepens, indicating that the pin-slot geometry reaches its optimal torque-transfer configuration. In this case, the driven wheel experiences significant angular motion even with minor angular displacement from the driver. The curve flattens when the pin approaches the trailing end of the slot near the conclusion of the cycle (0.12–0.157 s), which lowers torque and slows motion. The middle plot displays the angular velocity $\omega_{driven}(t)$, which starts at a peak of about 45–50°/s after engagement and then declines gradually. This peak results from an initially ideal torque arm and the driver's quick input. Each increase in driver rotation, however, results in a decrease in the driven wheel's angular velocity as the cycle progresses and the torque arm shortens. The velocity has dropped to almost zero by 0.157 seconds, indicating. The start of the dwell phase. A single frame from the animation visualisation of a 4-slot Geneva mechanism, showing the interaction between the driver pin and the driven wheel, is shown in Figure 5 (at t = 0.11 s). With a steady rotational speed of 10 rad/s, the red driver pin is now positioned just above the horizontal axis, having turned about 63°. While the

Geneva wheel (black circle) stays centred at (70.71 mm, 0), the black crank arm runs from the pin to the origin. The bold red segment indicates the active slot that is being driven at the moment, while two thin black spokes show the wheel's static orientation during dwell phases. The driven wheel's angular velocity is close to its peak because the lever arm is maximised due to the pin-slot alignment being almost perpendicular to the centre-to-centre line. Visually, the wheel is halfway through its 90° indexing stroke since the red slot has already rotated

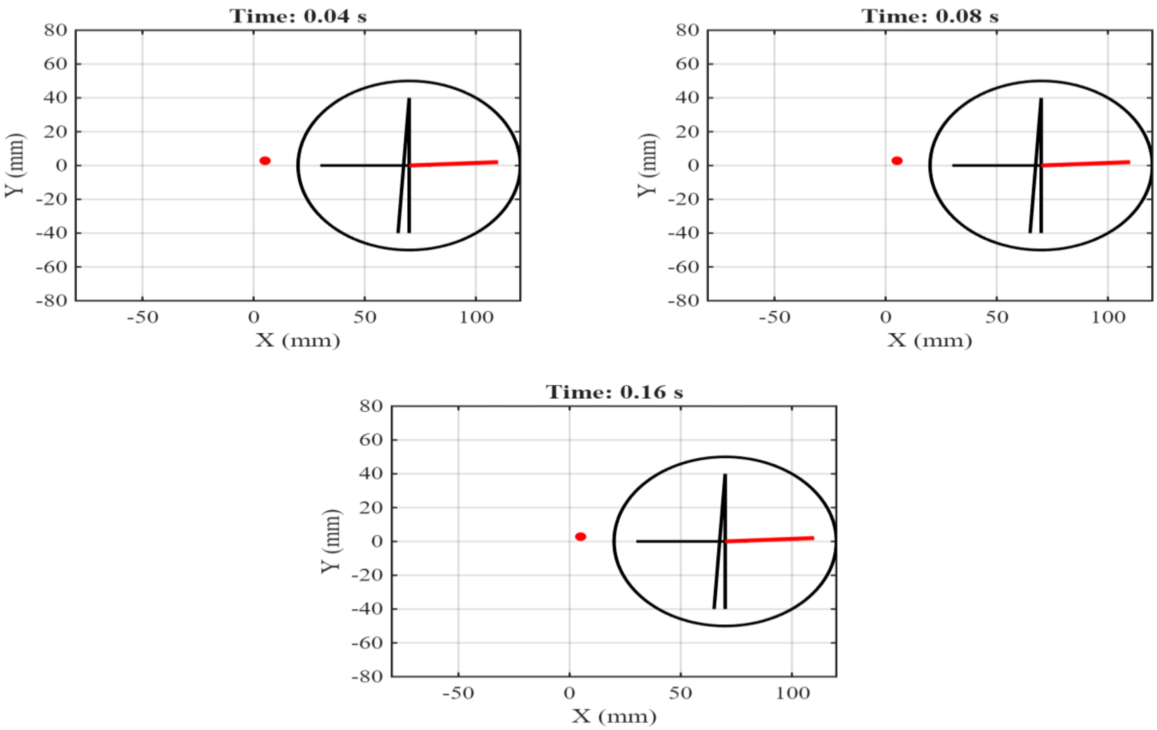

Figure 5. Visualisation: slot motion animation

several degrees clockwise from vertical. The lever arm will gradually shorten as the pin pushes the slot toward horizontal, lowering the wheel's speed and bringing it to rest at its new dwell position. Thus, the basic kinematics that characterise the intermittent motion of a Geneva mechanism—rapid mid-stroke rotation followed by smooth deceleration and final locking—are captured in this animation frame.

Optimization Analysis

Figure 6 compares the angular position $\theta_{driven}(t)$ of the driven wheel for Geneva mechanisms with slot counts N=4, 6, and 8 over one indexing cycle. With the centre distance modified for every configuration to preserve appropriate engagement geometry, each curve depicts motion under the same driver speed of 10 rad/s. The figure illustrates how slot count impacts motion characteristics and indexing length. The yellow curve for N=4 reaches nearly 4 degrees by $t \approx 0.157$ seconds, while the red and green curves for N=6 and N=8 reach about 2.5 and 1.5 degrees, respectively. This demonstrates unequivocally that mechanisms with more slots have slower results angles over identical driver angle input because their per-step indexing angle is less (90° for N = 4, 60° for N = 6, and 45° for N = 8). All curves have a similar shape, despite their varying magnitudes: a slow flattening near the end, a sharper slope in the middle, and a sluggish rise at the beginning. The shifting geometry of the pin-slot interaction gave it this shape. The torque arm is short early in the stroke, resulting in less rotation of the output. The torque arm lengthens, and angular motion accelerates as the driver rotates farther and the pin approaches perpendicular alignment with the driven wheel centerline. The output rate decreases further as the torque arm shortens toward the end. These variations in slope and curve form have significant design ramifications. Faster indexing is achieved with fewer slots, such as $N = 4$; however, higher dynamic loads are introduced due to rapid angular changes. Applications that require less vibration and a more gradual acceleration profile favour slower, smoother motion, which is produced by higher slot counts such as $N = 6$ or 8. Thus, indexing speed, smoothness, and mechanical stress must all be balanced while choosing the number of slots. The driven-wheel angular velocity $\omega_{driven}(t)$ for N = 4, 6, and 8 is compared in Figure 7. The yellow N = 4 curve decays to near zero after

0.157 s after peaking at about 44°/s. The maximum for N = 6 (red) is at 30°/s, and it drops to zero by about 0.104 s. The green N = 8 curve begins at about 23°/s and reaches zero at about 0.078 s. Higher slot counts hence result

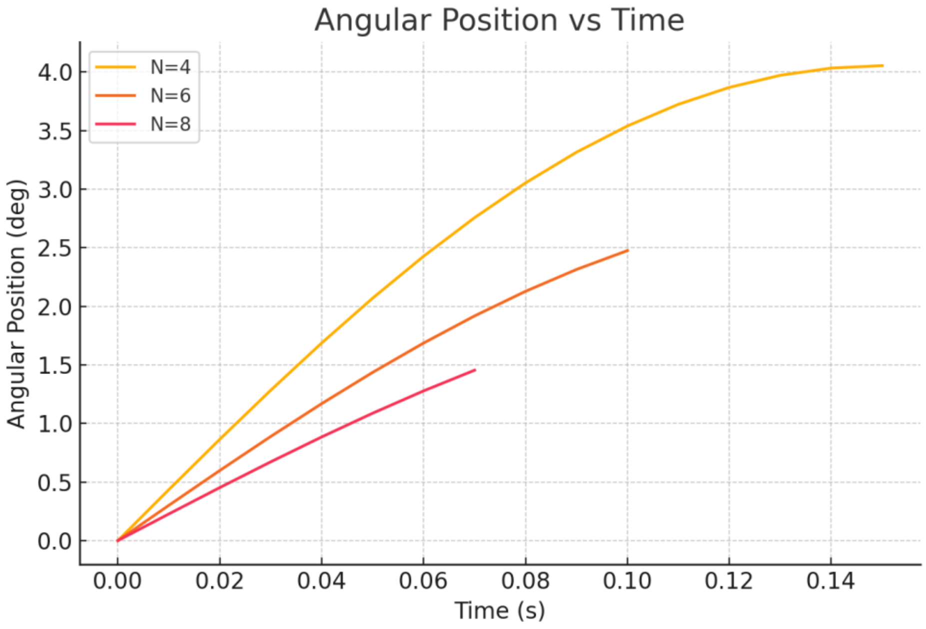

Figure 6. Angular Position Comparison (θ_{driven} vs t)

in quicker indexing times and lower peak velocities. To put it another way, N = 8 delivers smoother, slower motion over a shorter interval, whereas N = 4 offers the fastest speed but the longest indexing time

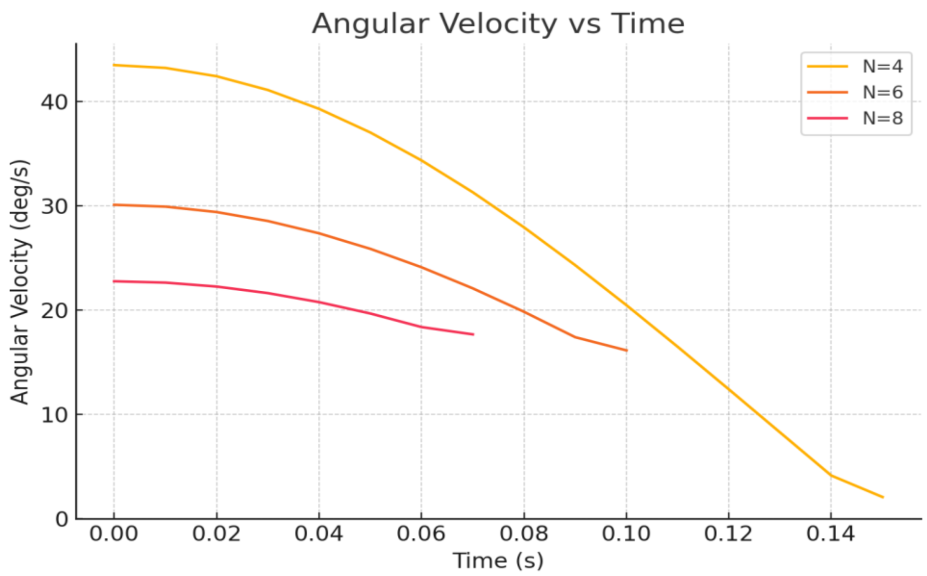

Figure 7. Angular Velocity Comparison (ω_{driven} vs t)

For N = 4 (yellow), N = 6 (red), and N = 8 (green), angular acceleration $\alpha_{driven}(t)$ is displayed in Figure 8. The N = 4 curve shows a considerable mid-stroke deceleration with the biggest negative peak at –420°/s² approximately 0.125 s. N = 8 peaks close to –170°/s² at 0.06 s, whereas N = 6 reaches almost –270°/s² at 0.08 s. Milder deceleration and shorter indexing times are observed with larger N values. This implies that a 4-slot design has the most dynamic shock, whereas adding slots (to 6 or 8) results in smoother motion with lower peak decelerations, which is advantageous for lowering wear and vibration. Similar PSO-ANN frameworks can enhance motion prediction[24].

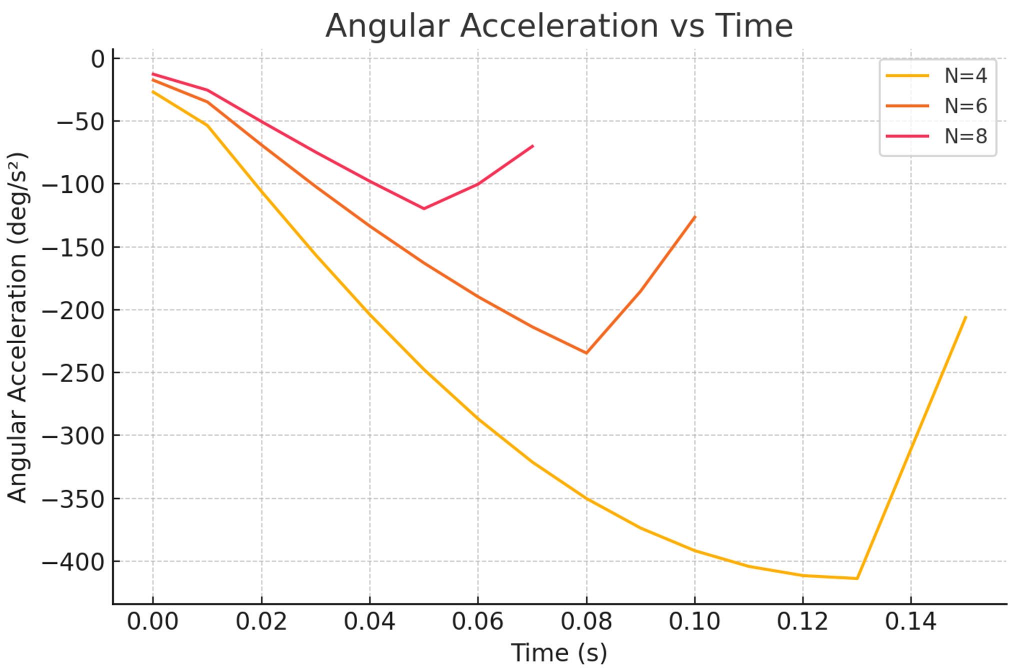

Figure 8. Angular Acceleration Comparison (α_{driven} vs t)

Comparison of configurations for N = 4, 6 and 8

Table 3 shows that N = 4, achieves the fastest angular output but imposes higher mechanical shock and inertial stress, making it less suitable for precision applications requiring smooth operation. While N = 6, provides a compromise between speed and smoothness, balancing performance for general automation purposes and N = 8, offers the smoothest indexing with the least mechanical stress, ideal for high-precision or vibration-sensitive environments despite slightly slower per-step angular output.

Table 3. Comparative Performance Summary of Geneva Mechanism Configurations (N = 4, 6, 8)

Slot Count (N)	**Indexing Angle per Event (°)**	**Index Time (s)**	**Peak Angular Velocity (°/s)**	**Peak Angular Acceleration (°/s²)**	**Characteristics**
4	90°	0.157	~ 44–45	≈420	Fastest output, highest dynamic stress
6	60°	0.104	~30	≈270	Balanced speed, reduced dynamic loads
8	45°	0.078	~23	≈170	Smoothest motion, minimal mechanical shock

Simulation Results – One Indexing Cycle

The dynamic performance of Geneva mechanisms for slot counts N=4, 6, and 8 is contrasted in Table 4. It contains a normalized smoothness index (derived from MATLAB simulation outputs), peak angular acceleration, velocity fluctuation, and estimated index duration. Despite a decrease in the indexing angle per step, the data show a distinct trend: the mechanism becomes smoother (lower acceleration peaks and reduced velocity fluctuations) as the number of slots increases. To illustrate the performance trade-offs between smooth motion (N = 6 or 8) and rapid indexing (N = 4), this table is essential. Simulation result shown in table N =4 shows highest acceleration (~420°/s²); N= 8 lowest (~170°/s²). Various indexing drives show similar trade-offs.

These reductions in acceleration peaks directly benefit applications where precision and longevity are critical, such as CNC indexing or robotics[25]. Although higher slot counts reduce acceleration and velocity fluctuation, they also reduce indexing angle per cycle and may require higher manufacturing precision due to smaller slot spacing. Therefore, the optimum slot count depends on whether speed or smoothness is prioritized.

Table 4. Simulation Results – One Indexing Cycle

Slot Count (N)	**Index Time (s)**	**Peak Accel (°/s²)**	**Velocity Fluctuation (°/s)**	**Smoothness Index**
4	0.157	~420	~18.0	0
6	0.104	~270	~6.0	0.36
8	0.078	~170	~2.5	0.6

Table 5 shows the evolution of the driven wheel's angular position over time for a Geneva arrangement with four slots. It displays the angular displacement values at significant points in time between 0 and 0.157 seconds (the entire indexing interval). The data confirms the simulation plot observations by demonstrating that the fastest changes take place in the middle of the stroke. This time-based analysis provides valuable insight into how motion develops throughout the course of the cycle and aids in validating the kinematic model.

Table 5. Angular Position at Key Time Points (N = 4 Example)

Time(s)	**Angular Position (°)**
0	0
0.04	0.8
0.08	2.45
0.12	4.1
0.157	5.00 (Final Angle)

Metrics for Performance Comparison

A comparison of Geneva mechanism performance parameters for slot counts N=4, 6, and 8 is shown in Figure 9. The first subplot indicates a quick and abrupt slowdown during indexing, with the peak angular acceleration for N=4 (around 420°/s²) being the largest. This value shows a smoother transition in the driven wheel's motion as slot count grows, decreasing notably for N=6 (~270 °/s²) and further for N=8 (~170 °/s²). N=4 exhibits the largest deviation from the mean speed (~18 °/s) in the second subplot, which shows angular velocity fluctuations. In contrast, N=6 and N=8 show much lesser fluctuations of roughly 6 °/s and 2.5 °/s, respectively. This implies that motion is steadier and more reliable when there are more slots. The smoothness index, a relative indicator of motion continuity, is highlighted in the third subplot. There is a baseline of N=4 (smoothness = 0), a moderate improvement of N=6 (~0.35), and the smoothest performance (~0.6) of N=8. These patterns unequivocally show that while adding more slots reduces the indexing angle at each step, it also improves motion smoothness and reduces dynamic stress. Therefore, designers must strike a compromise between the necessity for speed, which is encouraged by lower N, and mechanical stability and smoothness, which are enhanced by higher N.

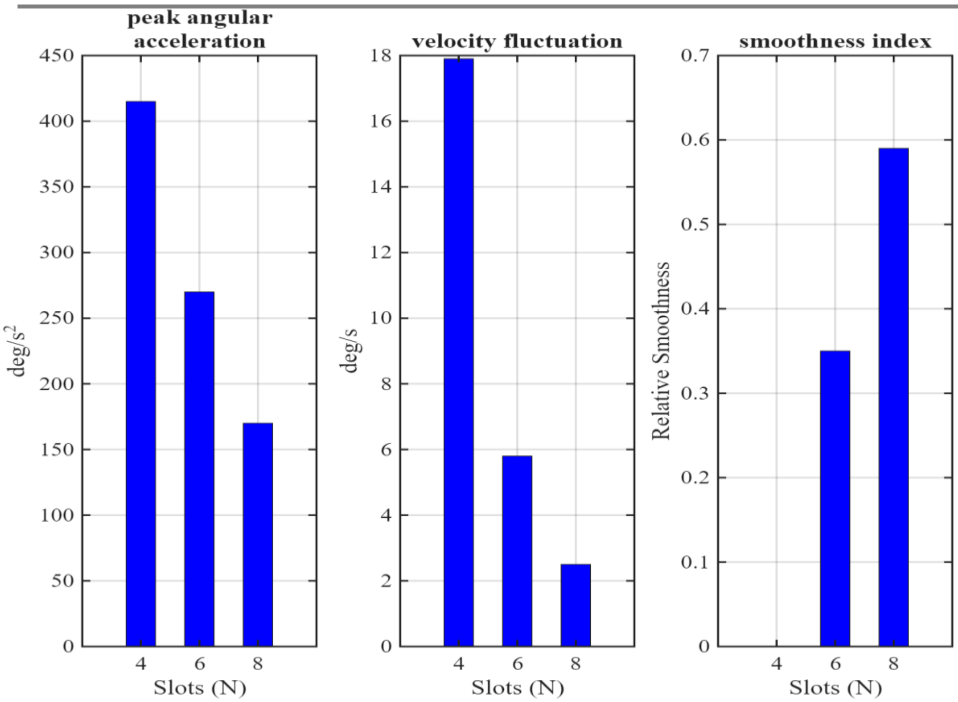

Figure 9. Slot Count vs. Performance Metrics

CONCLUSION

This study presents a systematic kinematic analysis of Geneva mechanisms with slot counts N = 4, 6, and 8, utilizing MATLAB simulations to evaluate the influence of slot number on motion smoothness and dynamic performance. The investigation focused on time-dependent angular displacement, velocity, and acceleration profiles, providing quantitative insights into performance trade-offs.

The key findings are summarized as follows:

- Increasing the slot count significantly reduces peak angular acceleration, from approximately –420°/s² (N = 4) to –170°/s² (N = 8), thereby minimizing mechanical shock and stress.
- Velocity fluctuation decreases markedly with higher slot counts, improving motion continuity (from ~18°/s at N = 4 to ~2.7°/s at N = 8).
- A smoothness index was introduced to quantify motion improvement, rising from 0 (N = 4) to 0.6 (N = 8).
- While N = 4 offers faster indexing per step (90° in ~0.157 s), it imposes greater dynamic loads, whereas N = 8 enables smoother, quieter operation suited for precision-driven applications.

The main contribution of this study is a comparative quantitative assessment of slot count effects on Geneva mechanism smoothness and dynamic response under identical simulation conditions. This work is limited to ideal kinematic simulation assuming rigid bodies, negligible friction, and no manufacturing clearance. Dynamic forces, wear, noise, and experimental validation were outside the present scope. Future research will extend this analysis to include: Experimental validation of simulation findings through physical prototypes. These extensions will provide deeper insights to inform Geneva mechanism optimization for high-precision, high-speed, and high-duty-cycle applications.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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REFERENCES

1. J. Yang et al., “Investigation of intermittent motion mechanisms in large landslides based on in-situ monitoring and microtremor survey,” Eng. Geol., vol. 354, p. 108117, Jul. 2025, doi: 10.1016/j.enggeo.2025.108117.
2. A. Chandra Shekhar, H. S. Shaik, and S. Shahab, “Analysis of Geneva mechanism using dwell symmetrical coupler curve mechanism,” Mater. Today Proc., vol. 39, pp. 1402–1406, Jan. 2021, doi: 10.1016/J.MATPR.2020.05.025.
3. D. Zhang, M. Reed, B. Li, Z. Gao, and Y. Ge, “Design optimization of a geneva mechanism for internal combustion engine application,” in 2009 International Conference on Information and Automation, IEEE, Jun. 2009, pp. 649–654. doi: 10.1109/ICINFA.2009.5205002.
4. D. Copaci, D. Blanco, and L. E. Moreno, “Flexible Shape-Memory Alloy-Based Actuator: Mechanical Design Optimization According to Application,” Actuators, vol. 8, no. 3, p. 63, Aug. 2019, doi: 10.3390/act8030063.
5. W. Lin, Y. Tsai, and K. Hsiao, “Optimum variable input speed for kinematic performance of Geneva mechanisms using teaching-learning-based optimization algorithm,” Proc. Inst. Mech. Eng. C J. Mech. Eng. Sci., vol. 231, no. 10, pp. 1871–1883, May 2017, doi: 10.1177/0954406215623307.
6. H. Chen, J. Zheng, S. Lu, S. Zeng, and S. Wei, “Design and experiment of vertical pneumatic fertilization system with spiral Geneva mechanism,” International Journal of Agricultural and Biological Engineering, vol. 14, no. 3, pp. 135–144, 2021, doi: 10.25165/j.ijabe.20211404.6575.
7. K. Saini, P. Patel, R. Bjapai, and S. Shoor, “Design and contact analysis of Geneva mechanism with different materials for automatic stamping by using FEA simulation,” 2025, p. 020001. doi: 10.1063/5.0243516.
8. W. Lin, Y. Tsai, and K. Hsiao, “A new indexing motion program for optimum designs of Geneva mechanisms with curved slots,” Proc. Inst. Mech. Eng. C J. Mech. Eng. Sci., vol. 231, no. 21, pp. 3974–3986, Nov. 2017, doi: 10.1177/0954406216656021.
9. H. Abdul, S. P. Bochu, and S. Pabba, “Design and Fabrication of Tool Changer Using Geneva Mechanism,” 2024, pp. 1–9. doi: 10.1007/978-981-97-4958-4_1.
10. I. Stănășel, F. Blaga, and T. Buidos, “Computer Aided Design of Classic External Geneva Mechanism,” Adv. Mat. Res., vol. 1036, pp. 662–667, Oct. 2014, doi: 10.4028/www.scientific.net/AMR.1036.662.
11. E. Zhang and L. Wang, “Parametric Design and Motion Analysis of Geneva Wheel Mechanism Based on the UG NX8.5,” in Proceedings of the 2017 International Conference on Manufacturing Engineering and Intelligent Materials (ICMEIM 2017), Paris, France: Atlantis Press, 2017. doi: 10.2991/icmeim-17.2017.59.
12. G. A. Ambaye and H. G. Lemu, “Numerical Stress Analysis and Fatigue Life Prediction of the Classical External Geneva Mechanism,” 2022, pp. 176–186. doi: 10.1007/978-981-19-0572-8_23.
13. F. I. Tiberiu Petrescu, T. M. Abu-Lebdeh, and A. Apicella, “Presentation of a Mechanism with a Maltese Cross (Geneva Driver),” American Journal of Engineering and Applied Sciences, vol. 11, no. 2, pp. 891–900, Feb. 2018, doi: 10.3844/ajeassp.2018.891.900.
14. G. Figliolini and P. Rea, “Effects of the design parameters on the synthesis of Geneva mechanisms,” Proc. Inst. Mech. Eng. C J. Mech. Eng. Sci., vol. 227, no. 9, pp. 2000–2009, Sep. 2013, doi: 10.1177/0954406212466194.
15. J. J. Lee and B. H. Jan, “Design of Geneva mechanisms with curved slots for non-undercutting manufacturing,” Mech. Mach. Theory, vol. 44, no. 6, pp. 1192–1200, Jun. 2009, doi: 10.1016/J.MECHMACHTHEORY.2008.09.003.
16. S. U. Bhaskar, K. P. R. Kumar, and D. K. Kumar, “Analysis on slot curvature and contact stresses on Geneva wheel,” 2021, p. 050018. doi: 10.1063/5.0058041.

17. T. Minh and T. Tran, "A prototype of paper cutting machine," Journal of Applied Engineering Science, vol. 23, no. 1, pp. 1–14, 2025, doi: 10.5937/jaes0-46220.
18. N. N. Swadi, "Kinematics Characteristics of The Internal & External Geneva Mechanism Under The Effect of Multi Design Parameters," 2016.
19. V. Pasika, P. Nosko, O. Nosko, O. Bashta, V. Heletiy, and V. Melnyk, "A method to synthesise groove cam Geneva mechanisms with increased dwell period," Proc. Inst. Mech. Eng. C J. Mech. Eng. Sci., vol. 238, no. 15, pp. 7544–7555, Aug. 2024, doi: 10.1177/09544062241234477.
20. A. Yerubayeva, E. Shehab, K. I. Malik, and Md. H. Ali, "Design and Development of 3D Printed Geneva Wheel Mechanism," in 2022 International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME), IEEE, Nov. 2022, pp. 1–8. doi: 10.1109/ICECCME55909.2022.9988520.
21. O. A. Dahunsi, A. Y. Oyerinde, O. P. Bodunde, P. Bodunde, and O. S. Olunloyo, "Kinematic Analysis and Design of a Geneva Stop Mechanism Teaching Aid for Intermittent Motion," 2017. [Online]. Available: https://www.researchgate.net/publication/351785823
22. D. B. Dooner, A. Palermo, and D. Mundo, "AN INTERMITTENT MOTION MECHANISM INCORPORATING A GENEVA WHEEL AND A GEAR TRAIN," Transactions of the Canadian Society for Mechanical Engineering, vol. 38, no. 3, pp. 359–372, Sep. 2014, doi: 10.1139/tcsme-2014-0026.
23. A. Chandra Shekhar, H. S. Shaik, and S. Shahab, "Analysis of Geneva mechanism using dwell symmetrical coupler curve mechanism," Mater. Today Proc., vol. 39, pp. 1402–1406, 2021, doi: 10.1016/j.matpr.2020.05.025.
24. M. A. Mohd Shukran, Y. Y. Chung, W.-C. Yeh, N. Wahid, and A. M. Ahmad Zaidi, "Image Classification Technique using Modified Particle Swarm Optimization," Mod. Appl. Sci., vol. 5, no. 5, Sep. 2011, doi: 10.5539/mas.v5n5p150.
25. M. Liu, F. Qian, J. Mi, and L. Zuo, "Dynamic interaction of energy-harvesting backpack and the human body to improve walking comfort," Mech. Syst. Signal Process., vol. 174, p. 109101, Jul. 2022, doi: 10.1016/j.ymssp.2022.109101.