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Modelling and Motion Analysis of an Automotive Seating Track Using Finite Element Analysis

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Abstract: This paper aims to improve the design of a seat slider mechanism for an automotive seating system. The seating track mechanism comprises various parts, such as the track bar, upper slider rail, lower slider rail, and locking/unlocking mechanism. The upper rail holds the seat and manikin weight, whereas the lower rail is secured with mounting brackets. A Computer-aided design model of the proposed modified locking/unlocking mechanism of the seating track is created and conducted Finite Element Analysis (FEA). Also, the study includes the motion and dynamic analysis of the seating track mechanism using the bond graph technique by considering the mechanism with an equivalent spring-mass-damper system. The FEA ensured the design strength and its safety regarding failure analysis, whereas the motion analysis confirmed the suitability of the mechanism's kinematics. It is found that the maximum stress is developed at the track bar, i.e., 186.35 MPa, whereas the track displacement reaches its final design position, i.e., 175 mm in 2 s, when the applied force on the track bar is 100 N and on each slider is 20 N. The study ensures an alternative spring-less locking/unlocking mechanism for the seat slider mechanism.

Keywords: Bond graphs; Finite element analysis; Motion analysis; Seat slider mechanism.

1. INTRODUCTION

The automotive industry has undergone significant changes in recent years, with a greater focus on enhancing passenger comfort and safety. The automotive seating system is a critical component that influences both aspects. A seat slider mechanism plays a crucial role in providing adjustability and comfort to passengers. However, the design of these mechanisms is often limited by factors such as excessive vibrations, limited adjustability options, and safety risks. Therefore, the development of an efficient and reliable seat slider mechanism is crucial for the success of automotive seating systems. In recent years, several researchers have published papers on various aspects of automotive seating systems, including comfort, safety, and performance.

One critical aspect of automotive seating systems is evaluating their consistency with the Computer Aided Design (CAD) models and 3-dimensional (3D) scans of the actual seats. For instance, authors in [1] developed an automated seat dimension evaluation system that can accurately evaluate the consistency between CAD models and 3D scans of vehicle seats. The system has the potential to significantly reduce the time and effort required for manual inspection. These systems help to identify any discrepancies between the design and the actual product and can assist in improving the quality of the seat design. Another critical aspect of automotive seating systems is their crashworthiness. Researchers have proposed several techniques to improve the crashworthiness of automotive seats [2]. One study investigated the impact of frontal sled testing on a newly designed vehicle seat track bracket. The study concluded that the new design improved the crashworthiness of the seat compared to the original design. A recent study proposed a method of improving the safety performance of car seats by combining finite element analysis (FEA) with experimental tests [3]. The study highlights the importance of accurately predicting the impact behavior of car seats during a crash and optimizing their design to improve occupant safety. FEA has emerged as a powerful tool for evaluating the structural performance of various components. Previously, many researchers used the well-known FEA for analysis the proposed CAD model [4-6]. Several researchers have employed FEA to analyse the dynamic characteristics of car seats and their impact on behavior during crashes. For instance, article [7] used the FEA tool to analyze the stress and deformation behavior of vehicle seats under different loading conditions. In addition to comfort and safety, the reliability and durability of automotive seats are also critical factors. In [8], authors analyzed the performance of automotive car chairs and proposed ways to improve their durability by using advanced materials and manufacturing techniques. Another important aspect of automotive seating systems is the comfort that they provide to occupants. Similarly, in the study [9], the optimization design of a driving seat based on body comfort is investigated, and the study proposes a novel approach for optimizing the seat design to improve passenger comfort. In the area of seat vibration analysis, the article [10] conducts a finite element study to evaluate the effect of vibration characteristics of an automotive seating system on ride comfort. The study investigates the dynamic behavior of the seat system and identifies the critical factors that affect ride comfort.

The Bond Graph technique is another approach that is useful in modeling the dynamics of mechanical systems, including seat slider mechanisms. The technique is particularly useful in the study of the interaction between different components in the mechanism, which is essential for understanding its behavior under different loading conditions [11, 12]. Several studies have utilized FEA and Bond Graph techniques to analyze the design and performance of seat slider mechanisms. For example, the foot mounting bracket of a seating system for a passenger vehicle is designed and analyzed using the bond graph technique in [13]. The development of a vehicle seat involves a multi-disciplinary approach that integrates various factors such as biomechanics, materials science, manufacturing, and design optimization. In recent years, several research studies have been conducted on vehicle seat design and analysis, including automated seat dimension evaluation systems, design and analysis of foot mounting brackets, and vibration studies in human-car seat systems [14]. In [14], the authors used a novel simulation technique to study the vibration characteristics of a human-car seat system. Furthermore, a new adaptive hybrid controller for vibration control of a vehicle seat suspension featuring MR damper was proposed [15]. The proposed controller was designed to adjust the damping force in real time to improve ride comfort. Other studies in this field include the analysis of dynamic characteristics of a slide seat in a precision machining center [16], effects of adjustment devices on the fore-and-aft mode of an automobile seat system [17], and design and optimization of upper and lower rails for automotive seat track mechanism [18, 19]. All these studies contribute to the advancement of vehicle seat design and analysis and the development of more efficient and comfortable seating systems. All these literatures use a conventional spring-based locking/unlocking mechanism for the seating track. Some literatures i.e. [10, 16] reported the failure analysis of the spring-based locking/unlocking mechanism when it was used for a long time due to the spring mechanism.

This work aims to analyse and improve the design of a seat slider mechanism for an automotive seating system by modifying the locking/unlocking mechanism of the seating track. The objectives include understanding the geometry of the mechanism, generating a CAD model of the proposed modified locking/unlocking mechanism of the seating track, conducting FEA and motion analysis for easy locking/unlocking mechanism, reduced weight, and simplified maintenance. The work also addresses safety risks and excessive vibrations associated with the previous design. The study will utilize FEA and Bond Graph techniques to model and analyze the dynamics of the mechanism under different loading conditions. The outcome of this work will be a more efficient and reliable seat slider mechanism that enhances passenger comfort and safety. The insights gained can also benefit in design of other mechanical systems in the automotive industry.

2. CAD MODELLING OF THE SEATING TRACK

To develop a CAD model of the seating track mechanism, the well-known reverse engineering methodology has been adopted. Reverse engineering is the process used to understand how previously created the equipment, methodology, or software. Essentially, it is the act of examining the inner workings of a system to replicate or improve its behaviour. The function of the seat track mechanism has been understood through reverse engineering, and a similar CAD model has been created using SolidWorks software. Figure 1 shows an old sear seating track and rail mechanism, and Figure 2 shows the CAD model of the same. The CAD model is developed according to the dimensions of the physical model of the seating track.

Figure 1. Reference seating track and rail mechanism.

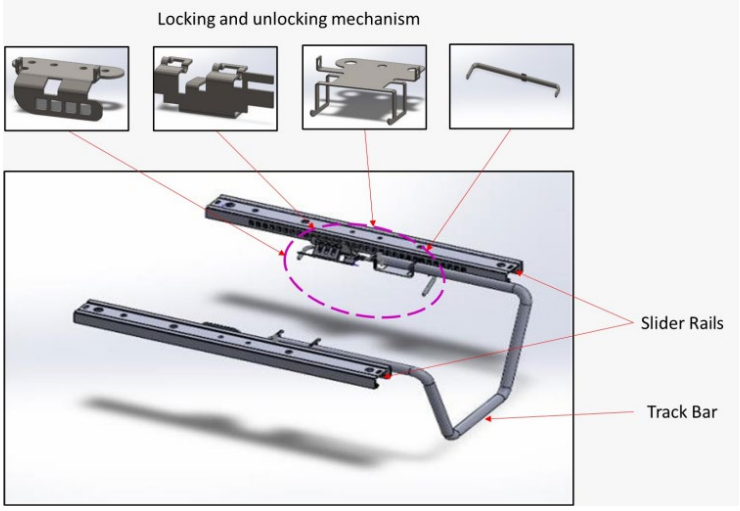


Figure 2. CAD model of the seating track and rail mechanism.

The seating track mechanism is composed of various parts, such as the track bar, slider rail, and locking mechanism, each having its unique function in the mechanism. The track bar is a U-shaped rod that plays a significant role in engaging/disengaging the locking system, allowing the slider to move on the rails and adjust the seat's position. To make the seat track mechanism work, a force is applied to the track bar and disengage the track from locking. The track bar is connected to the railing system through a spring system. Figure 2 shows the CAD model of the track bar. The sliding rail is responsible for providing the sliding motion of the seating track. There are two slider rails, the left-hand slider rail, and the right-hand slider rail. Each slider rail contains two components, one fixed with the seating stand and suspension system of the seat, while the other component travels in the forward direction. Both sliding rails are connected through the track bar, which is fixed with the locking/unlocking mechanism. The locking mechanism controls the travel length of the seating track. However, the function of the locking mechanism is complex, and it is an assembly of multiple components such as hooks, springs, and holders (refer Figure 2). The hook holds the slider and rails together to prevent any unwanted movement. When a force is applied to the track bar, the hook disengages, allowing the slider to move on the rails. Once the slider is moved to the desired position, the springs in the locking system engage the hook back to avoid any unwanted movement. The railing system is responsible for the movement of the seat backward and forward when the track bar is pulled.

The existing design of the seat slider mechanism in the automotive seating system had several challenges that affected the user experience and safety. These challenges included limited adjustment options, locking/unlocking mechanism failure due to the dependency on multiple springs, excessive vibrations, and lack of sufficient support and adjustability, which added complexity and made maintenance more challenging. Additionally, a part of the mechanism had a low factor of safety, posing a potential safety risk for the user. To address these challenges, several solutions were proposed, including the removal of springs from the locking/unlocking mechanism and the proposal of an alternative design for the locking and unlocking mechanism of the seating track.

The modifications made to the seat slider mechanism design included the simplification of the claw design, reduction in weight, and removal of dependency on springs (refer Figure 3). The claw design was simplified to reduce manufacturing time and cost while maintaining the same functionality of the mechanism. The weight of the design was decreased by removing unnecessary material while preserving its strength and durability. The dependency on springs was eliminated, and the mechanism was modified to improve adjustability and reduce vibrations. The locking hook works without the use of springs. When the track bar is pushed downward, the locking hook is disengaged from the engaged teeth of the track rail and allows the slider rail to move forward or backward direction. Besides, when the track bar is left off, the locking hook will engage the teeth of the track rail; as a result, the slider rail stops its movement and locks it at a specific point.

A comprehensive motion analysis has been performed to justify how the new mechanism will work. The motion analysis evaluates the movement and behavior of the seating track mechanism during various operating conditions, including adjustments, forward and backward motion, and locking and unlocking actions. The responses obtained from the motion analysis have been validated using the bond graph technique [8, 9], a powerful tool for analyzing the dynamic behavior of mechanical systems. This analysis provides a solid understanding of the functionality and performance of the new modified mechanism.

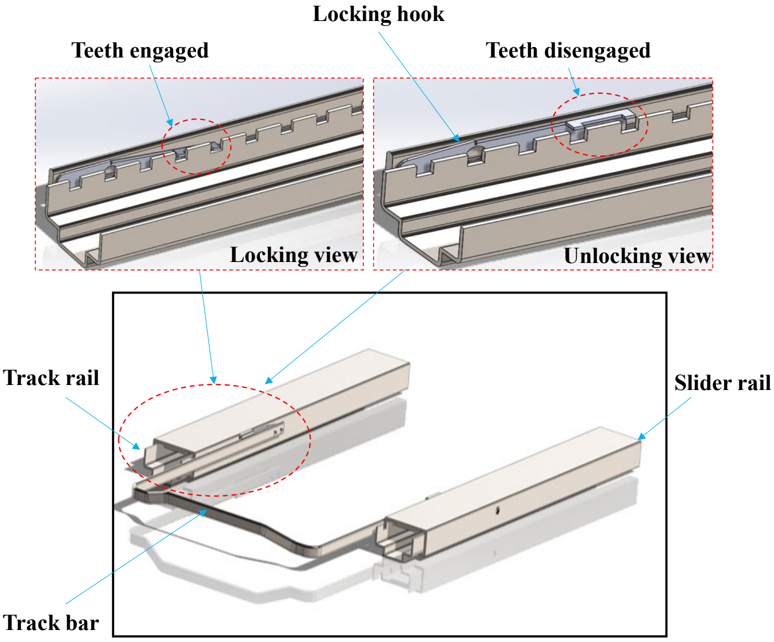


Figure 3. Proposed modified design of the seating track mechanism.

3. FINITE ELEMENT ANALYSIS OF THE PROPOSED SEATING TRACK MECHANISM

To conduct FEA, all parts of the seating track are assembled. It allowed analysis of the seating track mechanism's behavior under different loading conditions and optimizing its design for better performance. Using FEA, it can identify potential weak points or failure points in the design and make necessary adjustments before the actual production process. This help to ensure that the final product meets all required standards and is safe to use. The simulation also allows optimisation of the seating rail mechanism design, reduce material costs, and improve overall efficiency. Additionally, the behaviour of mechanical systems under various loading conditions can be studied. Overall, FEA played a key role in the research work, allowing thoroughly evaluating the design and performance of the seating rail mechanism and making the necessary improvements to ensure its safety and reliability.

Initially, the iges file of the CAD assembly model is imported into Ansys, and thereafter, the model is meshed by considering triangular elements having an element size of 200 mm. The total number of elements is 12150, and the material properties and boundary conditions are applied. The material property of any given material is crucial to perform FEA on any component. It helps to understand the behavior of the material under load conditions. In this study, a 201 Annealed Stainless Steel (SS) for the Seat Track Mechanism is considered. The material property of 201 Annealed Stainless Steel (SS) is given in Table 1. In conclusion, the material property of 201 Annealed Stainless Steel is suitable for the study. As the lower surface of the seating track is fixed to the seating stand, the lower surface is made fixed, and a force equivalent to the sum of the seat weight and the weight of a person is applied. Therefore, an approximately 981 N force is applied to the model.

The FEA results reveal that the maximum stress in the proposed CAD model of the seating track occurred in the middle of the track bar, with a value of 186.35 MPa, while the minimum stress was observed at the end curves of the track bar, with a value of 0.0002 MPa (refer Figure 4(a)). The maximum deformation was found to be 1.677 mm, occurring in the middle of the track bar, while the minimum deformation was 9.2162×10^{-16} mm (refer Figure 4(b)). Overall, the FEA of the complete proposed CAD model of the seating track provides valuable insights into the stress and deformation behavior of the slider mechanism under the loading condition of 951 N.

Table 1. Material properties.

Properties	**Value**	**Units**
Elastic Modulus	2.07×10^{11}	N/m^2
Poisson's Ratio	0.27	--
Mass Density	7860	kg/m^3
Tensile Strength	68.5×10^{7}	N/m^2
Yield Strength	29.2×10^{7}	N/m^2
Thermal Expansion Coefficient	$1.7\times10^{-0.5}$	/K
Hardening Factor	0.85	--

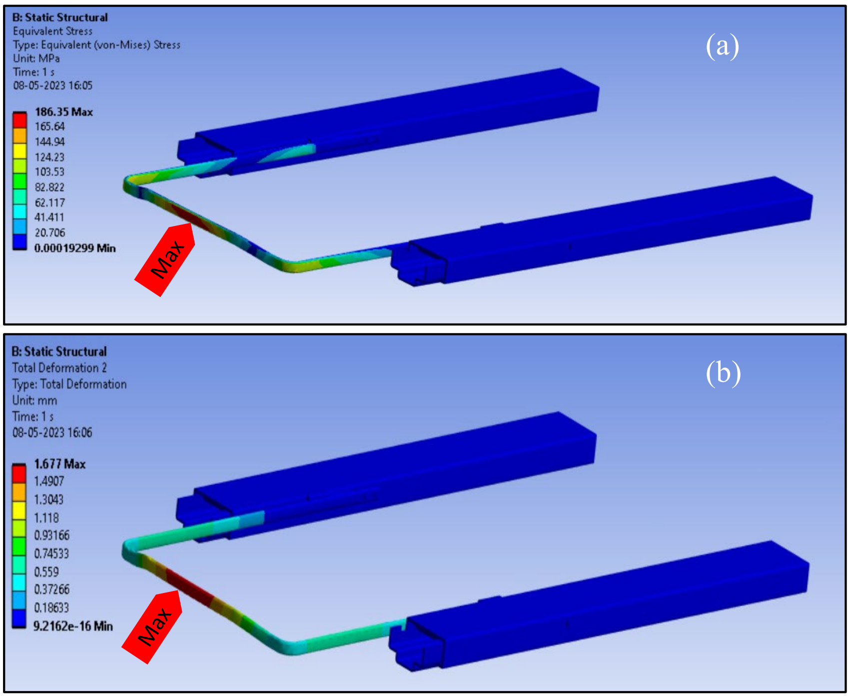


Figure 4. Proposed seating track under loading conditions of 981 N (a) Stress distribution (b) Deformation.

4. MOTION ANALYSIS OF THE SEATING TRACK BAR

Motion analysis is a powerful tool used to analyze the kinematics and dynamics of a moving system. By applying different sets of forces on the system and measuring the resulting displacement, velocity, acceleration, and friction force, a comprehensive understanding of the device's behavior can be obtained. The motion analysis of the seating track bar was performed using Solid-Works software to evaluate the kinematics and dynamics of the seating track mechanism. A series of forces were applied to the proposed seating track model, and resulting graphs of displacement, velocity, acceleration, and friction force vs time were generated. In the analysis, a force of 90 N on the track bar and 20 N on each slider are applied. The resulting graphs showed that the slider took approximately less than one second time to reach its final position (refer Figure 5(a)). From Figure 5(b), the velocity is constant when displacement is changed from 0 to 175 mm and thereafter, the velocity is zero. Similarly, from Figure 5(c), incremental acceleration is observed during the stated time and its value is zero when the track reaches its final position. In Figure 5(d), the friction force is slightly decreased during the travel of the seat track because the contact areas of the track rails are reduced. As normal, the friction force becomes zero when the seat track reaches its final position. As the seat track reaches its final position very quickly i.e. less than 1 sec., the result is not suitable.

For the subsequent analysis, the force on the track bar has been increased to 100 N and on each slider to 20 N. It has been observed that the slider reached its final position in 2 seconds (refer Figure 6(a)), and during the same time, the velocity is constant to 95 m/s (refer Figure 6(b)) and acceleration is zero (refer Figure 6(c)). Also, the friction force decreases slightly during traveling the seating track, and it becomes to zero after reaching its maximum travel length (refer Figure 6(d)).

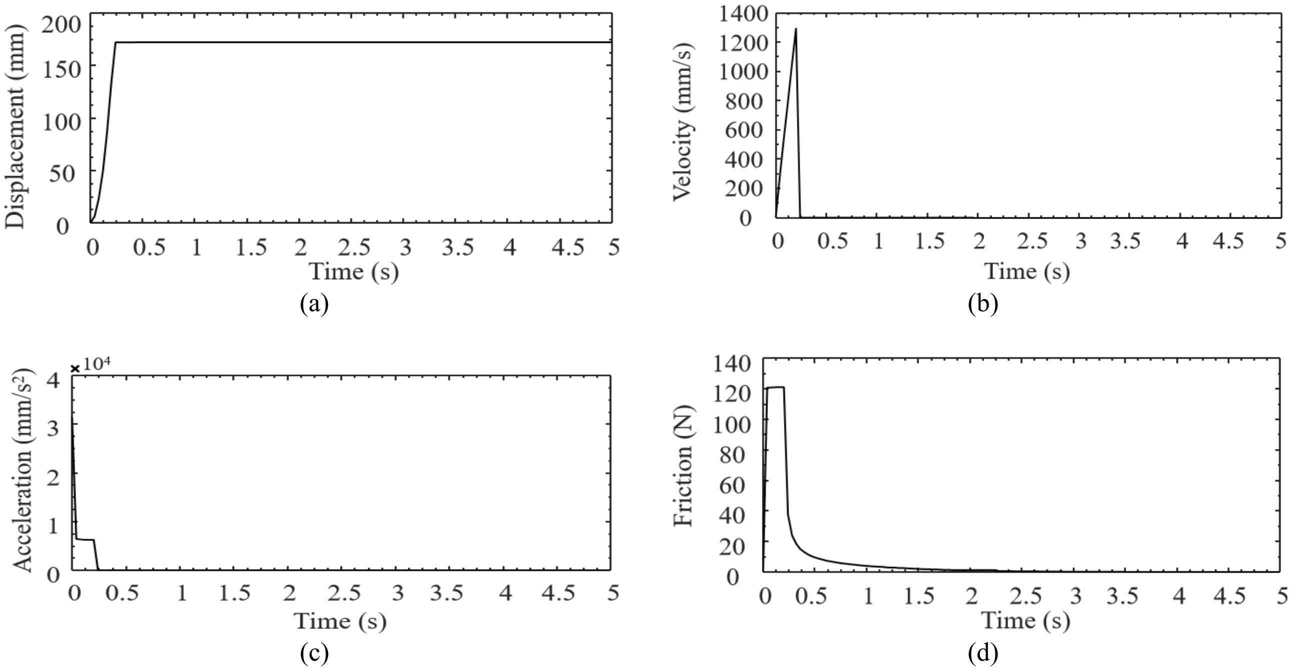
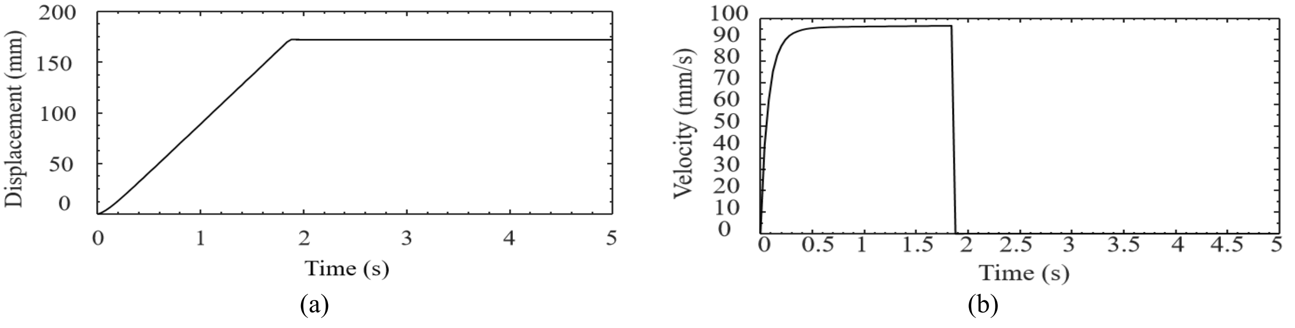
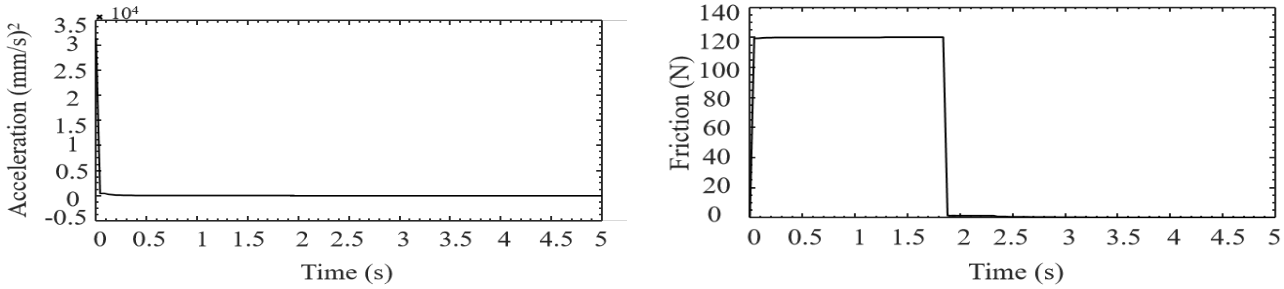


Figure 5. Responses when the force of 90 N on the track bar and 20 N on each slider, (a) Displacement (b) Velocity (c) Acceleration (d) Friction force.





(c) (d)

Figure 6. Responses when the force of 100 N on the track bar and 20 N on each slider, (a) Displacement, (b) Velocity, (c) Acceleration, (d) Friction force.

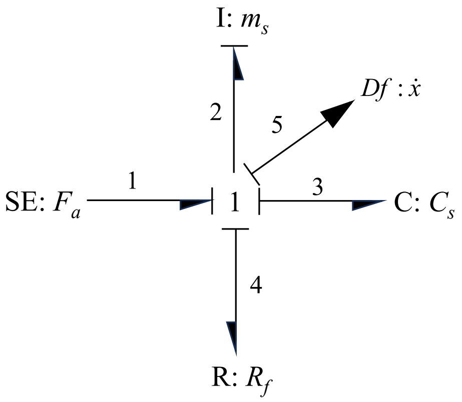


Figure 7. Equivalent bond graph model of the seating track mechanism.

5. VALIDATION OF THE SEATING TRACK MECHANISM USING BOND GRAPH TECHNIQUE

The seating track's forward and backward movement mechanism or the motion of the seating track, obtained from the motion analysis, is validated using the bond graph technique. The motion of the seat track is the equivalent mechanism of the spring-mass damper system. When manikin (driver/co-driver) applied a force on the track bar of the seating track, the slider rail starts to travel. As a result, the slider rail moves against friction force and rail stiffness, reducing the system's vibration. The dynamical model of the mechanism is developed using the bond graph technique (refer Figure 7). In Figure 7, SE element represents the force applied (F_a) to the track bar, R and C elements represent the frictional resistance (R_f) and the stiffness (C_s) of the mechanism, respectively. I element is representing the mass (m_s) of the seat and the manikin. The Df is the sensor, detected the velocity of the slider track ($\dot{x}$) of the system. The dynamic equation of the system is referred as

$$\ddot{x} = \frac{1}{m_s}[F_a - R_f\dot{x} - C_s x] \tag{1}$$

After developing the bond graph model and deriving the equation, the Symbols Shakti software [20] has been used to simulate the system's behavior. The simulation parameter value of the system is given as $F_a = 120$ N, $m_s = 80$ kg, $C_s = 1 \times 10^5$ N/m. The R_f varies due to the reduction of the area contacts with the travel of the seating track. The same values were applied in the motion analysis to simulate the system's behavior. The simulation was run for a duration of 10 seconds. In addition to the system parameters, the simulation time step was set to 0.01 seconds, which balances accuracy and computational efficiency. The simulation was initialized with an initial displacement of 0 meters and an initial velocity of 0 meters/second.

To validate the accuracy of the motion analysis of the proposed seat track, the displacement and velocity graphs obtained from the motion analysis simulation were compared with the responses obtained from the bond graph model (refer to Figures 8 and 9). The comparison showed that the two sets of graphs were nearly identical, confirming the reliability of the proposed seating track mechanism and its bond graph model for motion analysis. The error between these two sets of graphs is 4%. The addition of the velocity comparison graph (Figure 9) further strengthens the validation process. It demonstrates that the velocity responses obtained from the motion analysis and the bond graph model are in close agreement. This consistency between the two models reinforces the accuracy and reliability of the proposed seating track mechanism and its bond graph representation for motion analysis. The error between these two sets of graphs is 2.13%.

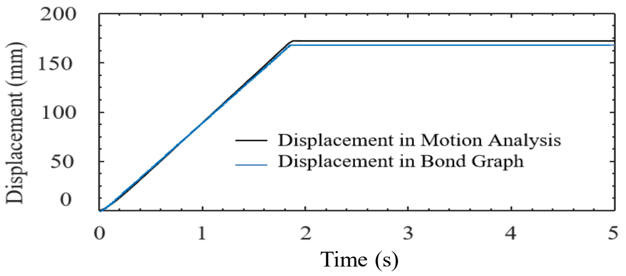


Figure 8. Comparison of displacement according to the data obtained from motion analysis and Bond graph model.

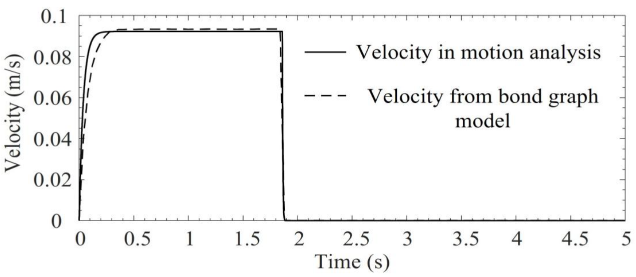


Figure 9. Comparison of velocity according to the data obtained from motion analysis and Bond graph model.

6. CONCLUSION

In this work, a thorough investigation of the seat track mechanism was conducted, and proposed a new concept or methodology for the locking/unlocking mechanism of it. An FEA analysis was performed on the proposed complete CAD model of the seat track mechanism to ensure the design strength and its safety regarding failure analysis. It also encompasses motion analysis, and the results are validated using bond graph model simulation. The work achieved significant insights and outcomes, which are as follows.

- The proposed CAD model of the locking/unlocking mechanism of the seating track provides an alternative mechanism for locking/unlocking, which eliminates the multiple spring's operation dependencies.
- The motion analysis provided valuable information regarding the behaviour and the performance of the proposed mechanism. Using the Bond Graph techniques, the seat track mechanism's forward and backward movements are modelled considering an equivalent spring-mass damper system.

A prototype model of the proposed locking/unlocking mechanism of the seating track may improve the readability and trust ability of the work. Hence, it can be suggested for future work.

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DECLARATION OF CONFLICTING INTERESTS

The authors declare no potential conflicts of interest with respect to the research and publication of this article.

REFERENCES

[1] J. Park, B. K. Park, B. C. Lee, B. Lee, M. Kwak and Y. Kim, Development of an automated seat dimension evaluation system, *SAE Technical Paper*, 2019-01-0401, 2019.

[2] O. O. Deveci and A. Durmus, Frontal impact sled testing of a new designed vehicle seat track bracket, *International Journal of Crashworthiness*, 27(1393), 2021, 1393-1400.

[3] L. Hongling, D. Yude, C. Changliang and C. Chao, Combined with finite element analysis of car seat safety performance improvement, *Journal of Science and Technology*, 35, 2021, 79-89.

[4] P. Bral, J. P. Tripathi, S. Dewangan and A. C. Mahato, CFD analysis of an exhaust manifold for emission reduction, *Materials Today: Proceedings*, 63, 2022, 354-361.

[5] O. Prakash and A. C. Mahato, Finite element analysis of the side bolster beam of the wagon tippler, *International Journal of Computer Aided Engineering and Technology*, 15(4), 2021, 553-564.

[6] A. Mittal, A. C. Mahato, M. Sharma, A. Mukhopadhyay and A. K. Kadian, Explicit dynamic frontal crash analysis of an all-terrain vehicle roll cage, *Applications of Modelling and Simulation*, 7, 2023, 85-92.

[7] A. D. Prabhu, A. S. Patil and A. D. Diwate, Finite element analysis of vehicle seat, *International Journal of Scientific Research and Engineering Trends*, 7(3), 2021, 1597-1600.

[8] P. C. S. Reddy, J. Shariff, M. Sreenivasan and E. R. Sivakumar, Analysis of automotive car chair, *Materials Today: Proceedings*, 45(7), 2021, 6895-6899.

[9] Y. Wang, Y. Wang, X. Niu and Y. Liu, Study on optimization design of drive seat based on body comfort, *Lecture Notes in Electrical Engineering* (*Man-Machine-Environment System Engineering*), 645, 2020, 301-306.

[10] M. Ramalingam and D. D. Jebaseelan, The effect of vibration characteristics of an automotive seating system on ride comfort, *Proceedings of the Institution of Mechanical Engineers Part D: Journal of Automobile Engineering*, 233(18), 2019, 6588-6601.

[11] A. Mukherjee, R. Karmakar and A. K. Samantaray, *Bond Graph in Modeling, Simulation and Fault Identification*, New Delhi: IK International, 2006.

[12] A. C. Mahato, S. K. Ghoshal and A. K. Samantaray, Bond graph modeling of soft switching concept and its parameters optimization, *International Journal of Modelling and Simulation*, 39(4), 2019, 223-233.

[13] S. N. Mahadik and V. S. Mahajan, Design and analysis of foot mounting bracket of seating system for passenger vehicle, *International Journal for Scientific Research and Development*, 6(4), 2018, 1377-1381.

[14] P. Mondal and S. Arunachalam, Vibration study in human car seat system, *Journal of Material Sciences and Engineering*, 7, 2018, 421.

[15] D. X. Phu, S. M. Choi and S.B. Choi, A new adaptive hybrid controller for vibration control of a vehicle seat suspension featuring MR damper, *Journal of Vibration and Control*, 23(20), 2016, 3392-3413.

[16] M. P. Sonwane and S. K. Bhor, Design and optimization of upper and lower rail for automotive seat track mechanism, *International Engineering Research Journal*, 2, 2015, 4220-4223.

[17] Z. Zhang, K. Jin, F. Li, C. Lu, G. Chai and D. Ye, Effects of adjustment devices on the fore-and-aft mode of an automobile seat system: headrest, height adjuster, recliner and track slide, *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, 230(8), 2016, 1140-1152.

[18] W. Wang, Analysis on dynamic characteristics of slide seat in precision machining center, *Academic Journal of Manufacturing Engineering*, 16(3), 2018, 29-35.

[19] B. K. D. Park, J. Park, B. C. Lee and B. Lee, Automated system for evaluating consistency between CAD model and 3D scan of vehicle seat, *Journal of Mechanical Science and Technology*, 36(2), 2022, 869-876.

[20] A. K. Samantaray and A. Mukherjee, *User's Manual of SYMBOLS Shakti*, High-Tech Consultants STEP Kharagpur Indian Institute of Technology, 2006.