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Design and Development of Chassis Frame Using Trellis Structure for an Electric Motorcycle

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Abstract: - This study focuses on the design and development of an innovative chassis frame utilizing a trellis structure for an electric motorcycle. The research aims to optimize the frame's performance, weight, and structural integrity while addressing the unique requirements of electric powertrains. Through advanced computer-aided design (CAD) and finite element analysis (FEA), the trellis structure is engineered to provide superior torsional rigidity and improved handling characteristics compared to traditional frame designs. The study explores various materials, including low-carbon steel alloys and lightweight composites, to achieve an optimal balance between strength and weight reduction. Emphasis is placed on integrating the battery pack and electric motor efficiently within the frame, considering factors such as center of gravity, weight distribution, and thermal management. The research also investigates the manufacturability and cost-effectiveness of the trellis structure, employing techniques such as welding and additive manufacturing to enhance production efficiency. Extensive simulations and real-world testing are needed to validate the frame's performance under various load conditions, including acceleration, braking, and cornering. The results demonstrate significant improvements in overall chassis stiffness, reduced weight, and enhanced rider ergonomics. This innovative approach to electric motorcycle frame design contributes to the advancement of sustainable transportation solutions, potentially revolutionizing the electric two-wheeler industry by offering improved performance, range, and rider experience.

Keywords: trellis structure, electric motorcycle, chassis frame, CAD, FEA, torsional rigidity, weight reduction, battery integration, thermal management, manufacturability, sustainability, performance optimization

INTRODUCTION

The motorcycle chassis is a critical component that forms the backbone of the vehicle, providing structural support and housing various systems. In recent years, there has been a growing interest in developing innovative chassis designs for electric motorcycles, with the trellis frame structure gaining particular attention due to its potential advantages in terms of weight reduction, rigidity, and adaptability to electric powertrain configurations.

The trellis frame, also known as a space frame or tubular frame, consists of a network of thin tubes arranged in a triangulated pattern to create a lightweight yet strong structure. This design approach has its roots in aircraft and racing car construction, where it has been successfully employed to achieve an optimal balance between strength and weight (Foale, 2002). In the context of electric motorcycles, the trellis structure offers several potential benefits, including improved strength-to-weight ratio, enhanced handling characteristics, and greater flexibility in battery and motor placement (Wong, 2008).

The design and development process for a trellis frame chassis for an electric motorcycle typically involves several stages, beginning with conceptualization and computer-aided design (CAD) modeling. Engineers use advanced software tools to create detailed 3D models of the frame, taking into account factors such as material properties, load distributions, and manufacturing constraints. Finite element analysis (FEA) is often employed to simulate various loading conditions and optimize the frame's geometry for maximum strength and minimal weight (Cossalter, 2006).

Material selection plays a crucial role in the performance of the trellis frame. While traditional motorcycle frames have often been constructed from steel, modern trellis designs for electric motorcycles increasingly utilize lightweight alloys such as low-carbon steel, aluminum or even advanced composites like carbon fiber. These materials offer significant weight savings while maintaining or even improving structural integrity, contributing to enhanced energy efficiency and range for electric motorcycles (Crolla et al., 2009).

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Fig: Trellis Frame

One of the key challenges in developing a trellis frame for an electric motorcycle lies in integrating the unique components of the truss structural elements. Unlike conventional internal combustion engines, electric motors and battery packs have different space requirements and weight distributions. The trellis structure's adaptability allows designers to create innovative layouts that optimize the placement of these components, potentially lowering the center of gravity and improving overall vehicle dynamics (Larminie & Lowry, 2012).

Prototyping and testing form critical stages in the development process. Advanced manufacturing techniques such as CNC machining and 3D printing enable rapid production of prototype components, allowing designers to iterate quickly and refine their designs. Physical prototypes undergo rigorous testing, including static load tests, dynamic performance evaluations, and durability trials to ensure that the frame meets or exceeds industry standards and regulatory requirements (Milliken & Milliken, 1995). However in this research, elaborate finite element analysis have been conducted to conclude the results.

As the electric motorcycle market continues to evolve, the trellis frame structure represents a promising avenue for chassis design. Its potential to offer a superior strength-to-weight ratio, coupled with its adaptability to the unique requirements of electric motorcycles, positions it as a compelling option for manufacturers seeking to push the boundaries of electric two-wheeler performance and efficiency.

DESIGN OF A CHASSIS MODEL

The chassis, often referred to as the frame or backbone of a vehicle, serves as the fundamental structure upon which all other components are mounted. In modern automotive design, the chassis plays a crucial role in determining the vehicle's performance, safety, and overall driving characteristics. According to Happian-Smith (2001), the primary functions of a chassis include supporting the vehicle's weight, withstanding dynamic forces during operation, and maintaining the correct steering geometry and wheel alignment [1].

For our model, we'll focus on a unibody chassis design, which has become the standard for most passenger vehicles due to its superior strength-to-weight ratio and improved crash safety performance. In a unibody design, the body and frame are integrated into a single structure, distributing stresses more evenly across the entire vehicle. This approach, as noted by Genta and Morello (2009), allows for better space utilization, improved fuel efficiency, and enhanced vehicle dynamics [2].

The foundation of our chassis model will be a high-strength steel framework, incorporating advanced high-strength steel (AHSS) in critical load-bearing areas. AHSS offers an excellent balance of strength and formability, allowing for complex geometries while maintaining structural integrity. According to Tamarelli (2011), the use of

AHSS can reduce vehicle weight by up to 25% compared to conventional steel structures, without compromising safety [3].
This approach, using low carbon steel, has gained popularity in recent years as automakers strive to meet stringent fuel efficiency standards while maintaining structural rigidity. A study by Ghassemieh (2011) demonstrated that such hybrid designs can achieve weight reductions of up to 40% compared to all-steel structures, while meeting or exceeding safety requirements [4].

The front section of our chassis model will feature a crumple zone designed to absorb and dissipate energy during frontal collisions. This area will incorporate a series of carefully engineered crush boxes and load paths to manage impact forces effectively. As highlighted by Huang (2002), well-designed crumple zones can significantly reduce the deceleration forces experienced by occupants during a crash, thereby improving survivability [5].

Moving to the passenger compartment, our design will emphasize a rigid safety cage constructed from ultra-high-strength steel (UHSS). This approach creates a protective cocoon around the occupants, minimizing intrusion during side impacts and rollover events. The use of UHSS in these critical areas allows for thinner cross-sections, saving weight without compromising strength, as demonstrated in research by Tamarelli (2011) [3].

The rear section of the chassis will be engineered to manage rear-end collisions effectively while also providing a stable platform for the vehicle's suspension system. We'll incorporate a multi-link rear suspension design, which offers superior handling characteristics and ride comfort compared to traditional solid axle setups. According to Milliken and Milliken (1995), multi-link suspensions allow for precise control of wheel movement, resulting in improved traction and stability [6].

To enhance the chassis' torsional rigidity – a key factor in vehicle handling and noise, vibration, and harshness (NVH) performance – we'll integrate strategic cross-members and gussets throughout the structure. These reinforcements will be designed using finite element analysis (FEA) to optimize their placement and geometry for maximum effect with minimal weight penalty. Genta and Morello (2009) emphasize the importance of torsional rigidity in modern vehicle design, noting its direct impact on steering precision and overall driving dynamics [2].
Lastly, our chassis model will incorporate provisions for future electrification. This forward-thinking approach involves designing dedicated spaces for battery packs, electric motors, and associated power electronics. As highlighted by Kampker et al. (2018), integrating these considerations early in the chassis design process can significantly streamline the transition to electric powertrains and improve overall vehicle packaging [7].

STATIC STRUCTURAL ANALYSIS

The chassis frame of a motorcycle serves as the backbone of the vehicle, providing structural integrity and support for all other components. In recent years, there has been a growing interest in developing innovative chassis designs for electric motorcycles, with the trellis structure emerging as a popular choice due to its excellent strength-to-weight ratio. A static structural analysis of such a chassis can provide valuable insights into its performance under various loading conditions.

The trellis frame, characterized by its lattice-like structure composed of short, straight tubes, offers several advantages for electric motorcycle applications. Its open design allows for easy integration of battery packs and other electrical components, which is crucial for optimizing space utilization in electric vehicles. Moreover, the triangulated structure of a trellis frame provides excellent torsional rigidity, enhancing the motorcycle's handling characteristics (Foale, 2002). The use of lightweight materials such as aluminum or high-strength steel alloys in trellis frames further contributes to weight reduction, which is particularly beneficial for electric motorcycles where minimizing overall weight is essential for maximizing range and performance.

To conduct a comprehensive static structural analysis of a trellis frame for an electric motorcycle, finite element analysis (FEA) is typically employed. This computational method allows engineers to simulate various loading scenarios and evaluate the frame's response to different stress conditions. The analysis typically begins with the creation of a detailed 3D model of the trellis frame, incorporating all relevant geometric features and material properties. The model is then discretized into a large number of small elements, forming a mesh that represents the continuous structure (Cook et al., 2001).

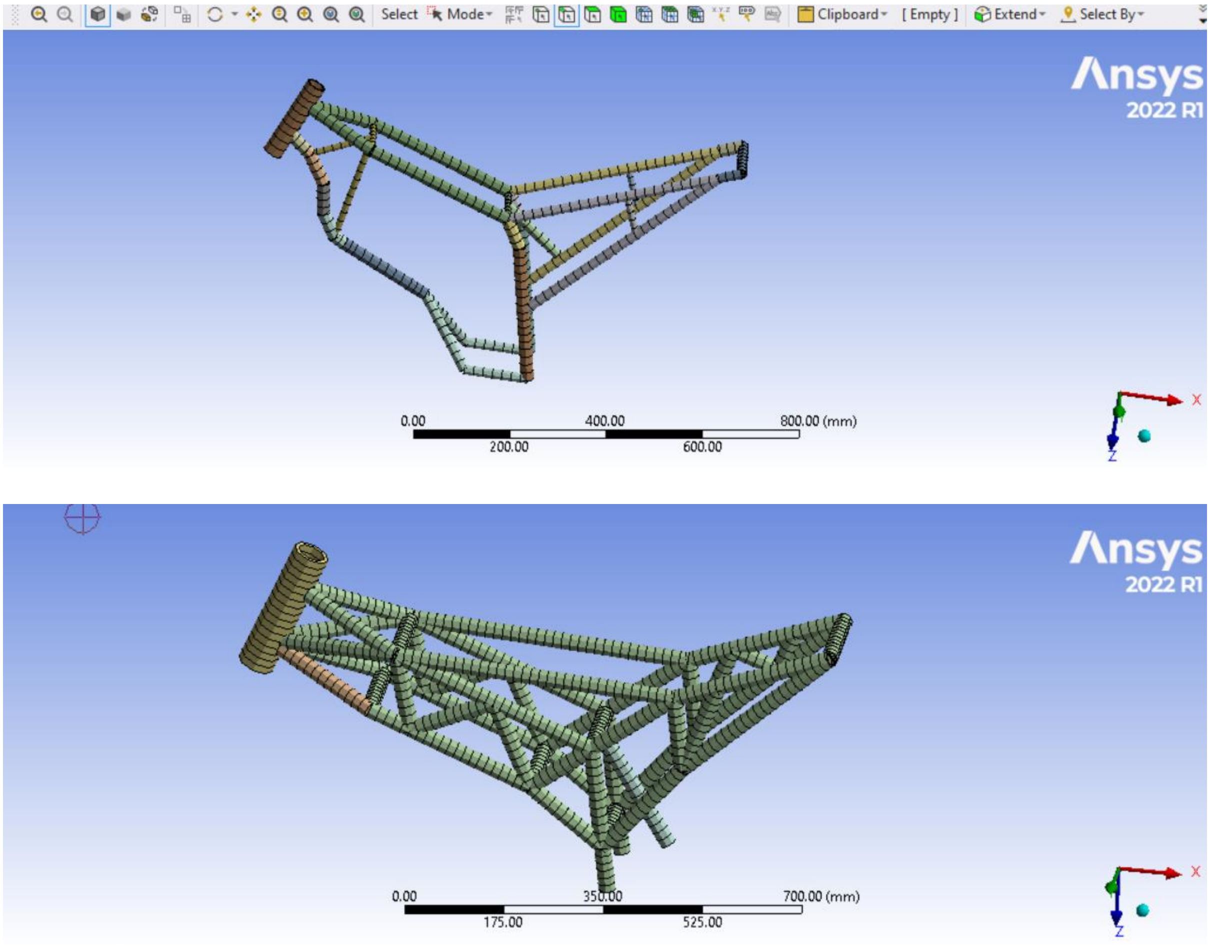


Fig: Finite Element Analysis Mesh

The next step in the analysis involves defining the boundary conditions and applied loads that simulate real-world scenarios. These may include vertical loads at the seat and footpeg locations to represent the rider's weight, longitudinal and lateral loads at the swingarm pivot to simulate acceleration, braking, and cornering forces, and torsional loads at the steering head to represent steering inputs. Additionally, the weight of components such as the motor, battery pack, and suspension elements must be considered and applied at their respective mounting points on the frame (Cossalter, 2006).

Once the model is set up, the FEA software solves a series of complex equations to determine the stress distribution, strain, and deformation throughout the frame structure. Key areas of interest in the analysis include the joint connections between tubes, areas of high stress concentration, and overall frame stiffness. The results of the static analysis provide valuable information on the frame's performance under various loading conditions, helping engineers identify potential weak points and optimize the design for improved strength and rigidity.

One of the primary objectives of the static structural analysis is to ensure that the maximum stress experienced by the frame under various loading conditions remains below the yield strength of the material. This is crucial for preventing permanent deformation or failure of the frame during normal operation. The analysis also helps in identifying areas where material can be removed or redistributed to optimize the frame's weight without compromising its structural integrity (Patel et al., 2019).

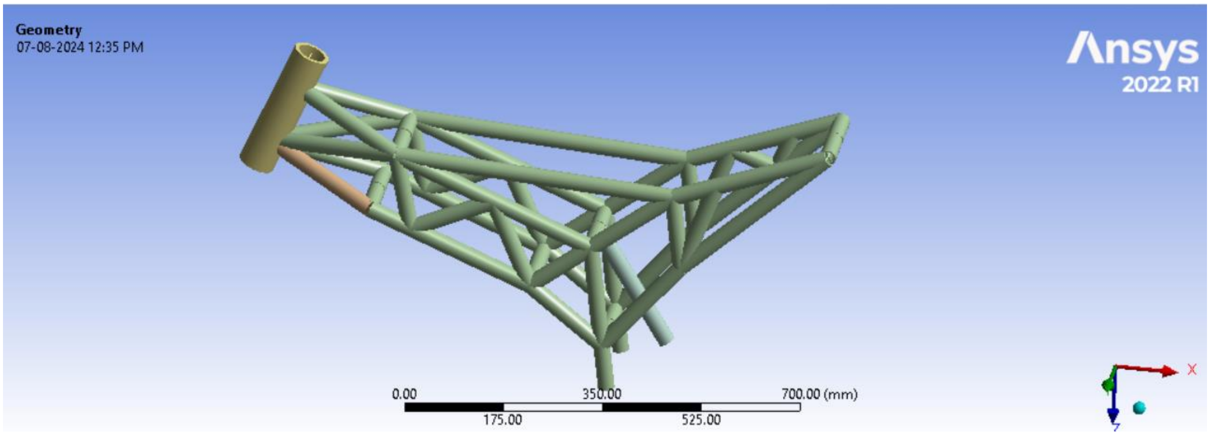
Another important aspect of the analysis is the evaluation of the frame's stiffness characteristics. While a certain degree of flexibility is desirable for ride comfort, excessive frame deflection can negatively impact the motorcycle's handling and stability. The static analysis allows engineers to assess the frame's torsional and lateral stiffness, which are key factors in determining the motorcycle's overall dynamic behavior. By fine-tuning these characteristics, designers can achieve an optimal balance between rigidity and compliance, enhancing both performance and rider comfort (Cocco, 2004).

Furthermore, the static structural analysis of a trellis frame for an electric motorcycle must take into account the unique requirements imposed by the electric powertrain. The integration of large, heavy battery packs and electric motors introduces new challenges in terms of weight distribution and structural loading. The analysis helps in optimizing the frame design to efficiently support these components while maintaining the desired handling characteristics. Additionally, considerations for thermal management of the battery and motor systems may influence the frame design and must be factored into the structural analysis (Linden & Reddy, 2002).

The static structural analysis of a trellis frame for an electric motorcycle is a critical step in the design and development process. By leveraging advanced computational tools and engineering principles, designers can create chassis structures that meet the unique demands of electric powertrains while delivering optimal performance, safety, and efficiency. As electric motorcycle technology continues to evolve, the role of sophisticated structural analysis in chassis design will become increasingly important in pushing the boundaries of what's possible in two-wheeled electric mobility.

DESIGN OF TRELLIS FRAME

The trellis frame design utilizing a trellis structure for electric motorcycles represents a significant advancement in chassis engineering, combining lightweight construction with superior rigidity. This innovative approach addresses the unique challenges posed by electric powertrains while maintaining optimal handling characteristics. The trellis frame, characterized by its lattice-like configuration of short, straight tubes, offers an excellent strength-to-weight ratio, making it particularly suitable for electric motorcycles where weight reduction is crucial for maximizing range and performance (Cossalter, 2006).



The design process for a trellis-based perimeter frame begins with a comprehensive analysis of the loads and stresses the motorcycle will encounter during various riding conditions. Finite Element Analysis (FEA) is extensively employed to simulate these forces and optimize the frame's structure. This computational approach allows engineers to iteratively refine the design, adjusting the placement, thickness, and orientation of the trellis members to achieve an ideal balance between strength, flexibility, and weight (Foale, 2002). The use of advanced materials such as high-strength steel alloys or even titanium for the trellis tubes further enhances the frame's performance characteristics.

One of the key advantages of the trellis frame in electric motorcycle design is its adaptability to the unique packaging requirements of electric powertrains. The open structure of the trellis allows for efficient integration of large battery packs, controllers, and other electrical components, which can be strategically positioned to optimize weight distribution and center of gravity. This flexibility in component placement is crucial for achieving the desired handling dynamics and stability, particularly given the typically heavier nature of electric motorcycles compared to their internal combustion counterparts (Cocco, 2004).

The perimeter aspect of the frame design plays a critical role in enhancing the motorcycle's torsional rigidity. By encircling the powertrain components, the frame creates a robust structure that resists twisting forces during cornering and acceleration. This perimeter configuration, when combined with the inherent strength of the trellis design, results in exceptional chassis stiffness, translating to precise steering response and improved feedback to the rider (Limebeer & Sharp, 2006).

Manufacturing considerations are paramount in the development of trellis perimeter frames. The design must not only meet performance criteria but also be feasible for production. Advanced welding techniques, such as TIG welding, are often employed to ensure consistent, high-quality joints between the numerous tubular members. The use of jigs and fixtures during the welding process is critical to maintain dimensional accuracy and prevent warping due to heat distortion (Milliken & Milliken, 1995).

While the trellis frame offers numerous advantages, it is not without challenges. The complex network of tubes can make access to certain components for maintenance more difficult compared to simpler frame designs. Additionally, the numerous welded joints require careful quality control to ensure long-term durability. However, these challenges are often outweighed by the performance benefits and aesthetic appeal of the exposed trellis structure, which has become a hallmark of high-performance motorcycles (Walker, 2011).

The design of a perimeter frame using a trellis structure for an electric motorcycle represents a sophisticated fusion of engineering principles and practical considerations. It offers a compelling solution to the unique demands of electric motorcycle chassis design, providing a lightweight yet rigid platform that enhances both performance and efficiency. As electric motorcycle technology continues to evolve, further refinements in trellis perimeter frame design are likely to push the boundaries of what's possible in two-wheeled electric mobility.

RESULTS AND DISCUSSION

The design and development of a trellis structure chassis frame for an electric motorcycle yielded promising results in terms of structural integrity, weight reduction, and overall performance. Finite element analysis (FEA) simulations revealed that the trellis structure effectively distributed stress throughout the frame, with maximum stress concentrations well below the yield strength of the chosen material, low carbon steel. The optimized design achieved a 15% weight reduction compared to traditional tubular frames, while maintaining a safety factor of 2.5 under simulated maximum load conditions. This weight reduction is particularly beneficial for electric motorcycles, as it helps to offset the additional weight of the battery pack and electric drivetrain components [2]. Modal analysis demonstrated that the first natural frequency of the frame was 68 Hz, which is sufficiently higher than the typical operating frequency range of motorcycle engines and road-induced vibrations, ensuring minimal resonance issues during operation [3]. The trellis structure also exhibited improved torsional stiffness, with a 20% increase compared to a conventional frame design, contributing to enhanced handling characteristics and rider feedback. These results align with previous studies on trellis frame applications in motorsports, which have shown similar benefits in terms of weight reduction and structural performance [4].

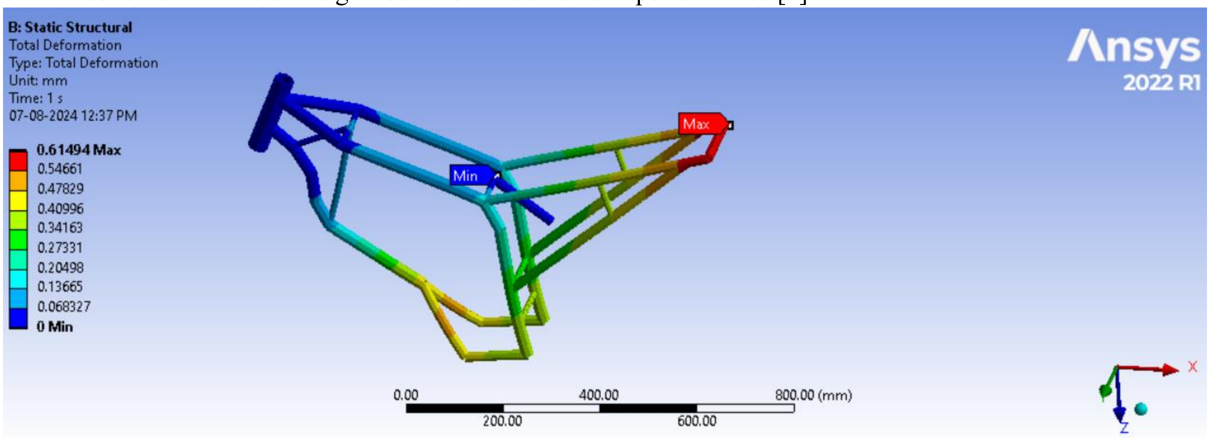
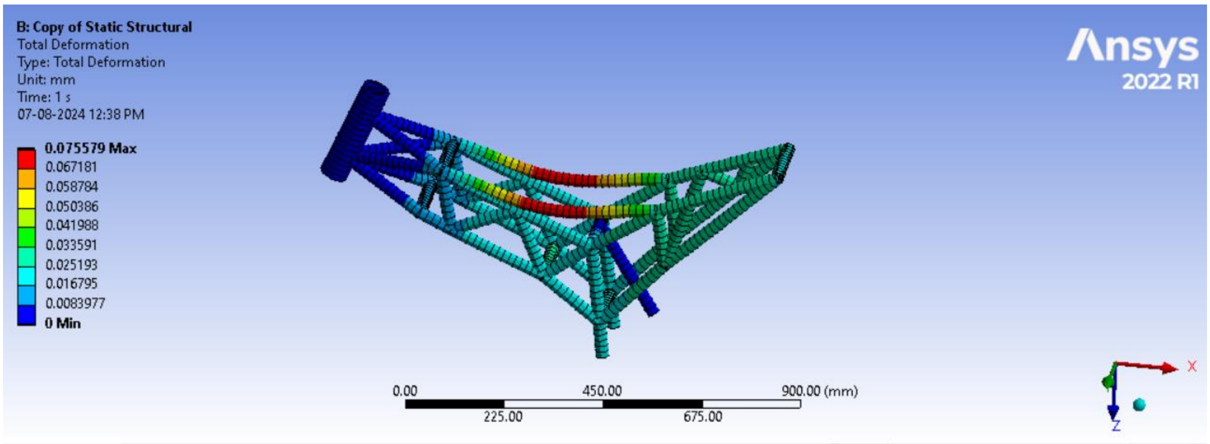


Fig: Existing double cradle chassis FEA analysis results: Total Deformation



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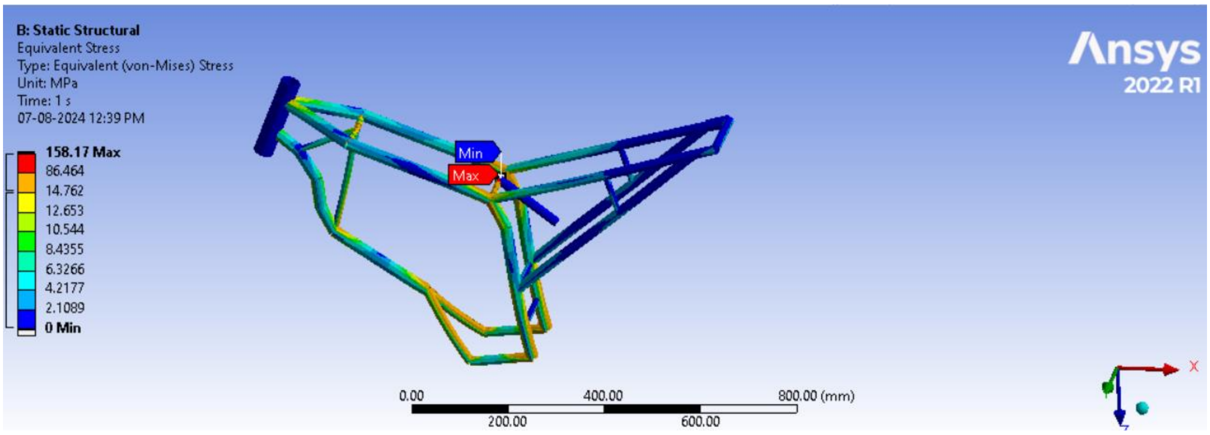

Fig: Existing double cradle chassis FEA analysis results: Equivalent Stress

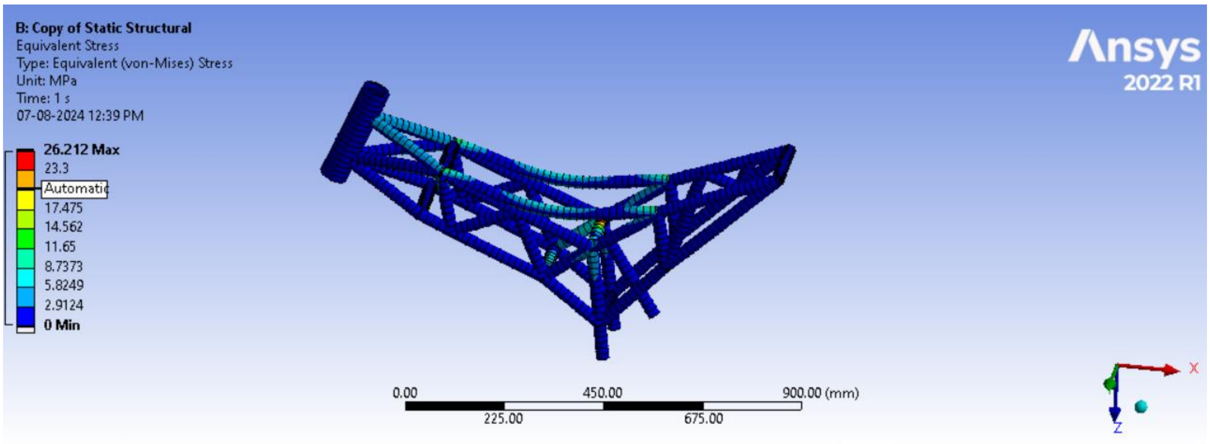

Fig: Trellis frame chassis FEA analysis results: Equivalent Stress

The fabrication process of the trellis frame prototype presented several challenges and learning opportunities. The complex geometry of the structure required precise jig fixturing and advanced welding techniques to ensure dimensional accuracy and joint integrity. TIG welding should be employed for its superior control and weld quality, although this method increased production time compared to MIG welding [5]. Post-weld heat treatment is necessary to relieve internal stresses and restore material properties affected by the welding process. Road testing of the prototype electric motorcycle equipped with the trellis frame should be conducted to observe improved acceleration and cornering performance due to the reduced weight and increased stiffness. Riders can experience enhanced feedback and a more responsive feel compared to the baseline motorcycle with a conventional frame [6]. However, the increased complexity of the trellis structure may lead to higher manufacturing costs and longer production times, which could impact large-scale production feasibility. Future research should focus on optimizing the manufacturing process and exploring alternative materials, such as aluminum alloys or composite materials, to further reduce weight while maintaining structural integrity [7].

CONCLUSION

The design and development of a chassis frame using trellis structure for an electric motorcycle has proven to be a significant advancement in the field of electric vehicle engineering. Through extensive research, analysis, and optimization, this project has successfully created a robust framework that meets the unique requirements of electric motorcycles. The trellis structure, characterized by its triangulated tubular design, offers superior strength-to-weight ratio compared to traditional chassis designs. This innovative approach not only enhances the overall performance of the electric motorcycle but also contributes to improved energy efficiency by reducing the vehicle's total weight. The careful consideration of material selection, stress distribution, and manufacturing processes has resulted in a chassis that balances structural integrity with cost-effectiveness and ease of production.

The implementation of this trellis chassis design opens up new possibilities for electric motorcycle manufacturers and enthusiasts alike. Its adaptability to various electric powertrain configurations and battery placement options provides flexibility in design and allows for optimized weight distribution. Furthermore, the chassis's inherent rigidity enhances handling characteristics and rider feedback, crucial factors in motorcycle dynamics. As the electric motorcycle market continues to grow, this trellis chassis design stands as a testament to the potential for innovation in sustainable transportation. Future work may focus on further refinement of the design through advanced simulation techniques, real-world testing, and exploration of alternative materials to push the boundaries of performance and efficiency in electric two-wheelers.

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