



## FINITE ELEMENT ANALYSIS OF REDESIGNED PIPE-WRENCH FOR OILFIELD SERVICING

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### Abstract

The reliability and efficiency of tools utilized in oilfield servicing have become a critical need. This work focuses on the optimization of pipe wrenches to meet the unique needs of oilfield service professionals. Pipe wrenches are indispensable tools for manipulating pipes and fittings in this industry, but there is significant room for improvement in their design and functionality. This study involves a comprehensive analysis of current pipe wrenches, considering factors such as adjustability, durability, ergonomics, and user-friendliness. By engaging with experienced professionals in the oilfield servicing sector, specific requirements encountered when using pipe wrenches in their daily operations were identified. Leveraging advanced methodologies, the design of the pipe wrench was done using SolidWorks software. Subsequent performance testing was conducted using ANSYS, subjecting the tool to a load of 900 N and also the optimized pipe wrench proved its strength during testing with different torque loads, showing it can handle pressure without breaking. This testing phase incorporated topology optimization techniques, resulting in a 13.5% reduction in material from 0.1406 kg to 0.1215 kg, while preserving the material's inherent strength. Additionally, the redesigned pipe-wrench integrates light emitting diode LED lighting for enhanced functionality and visibility in challenging environments.

**Keywords:** Pipe-wrench; Redesign; Finite element analysis; Reliability; Ergonomics; Oilfield

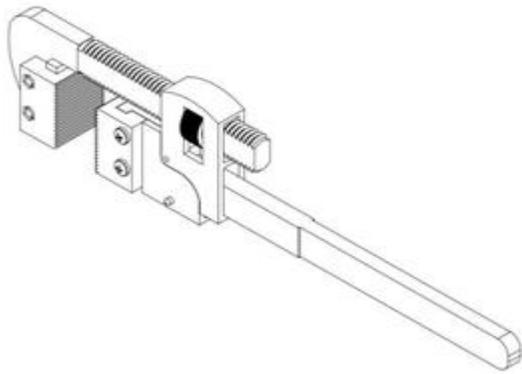
### Introduction

The oil and gas industry are indeed one of the largest and most influential sectors in the world economy. According to the International Energy Agency (IEA), oil and gas account for around 57% of the world's total energy consumption (Ho et al., 2020).

Globally, oil and gas industry being a cornerstone of energy production, relies on oil field servicing companies for infrastructure maintenance and optimization. Pipe wrenches, crucial tools in this sector, face operational challenges impacting efficiency and safety (Agrawal et al., 2023). Their adaptability to diverse pipe sizes and materials underscores their universality (Anderson, 2021), contributing to the efficiency of oil field infrastructure. Technological advancements in the industry, including digitalization and data analytics, reshape operations through predictive maintenance and enhanced decision-making (Frazier, 2015). Automation and robotics, such as autonomous drilling rigs and remotely operated vehicles, improve safety and efficiency (Garcia, 2021; Huang et al., 2018).

Pipe wrench optimization becomes pivotal for energy-efficient and sustainable oil field operations (Konda, 2020). Studies suggest that enhancing energy efficiency significantly reduces costs and improves profitability in oil servicing companies (Anderson, 2021). Innovations in drilling fluids, such as environmentally sensitive "green muds," minimize environmental impact (Johnson, 2022). Subsea technologies transform offshore operations, reducing the environmental footprint while ensuring efficient resource extraction. Environmental monitoring and remediation technologies reflect the industry's commitment to mitigating its impact on ecosystems (Mohamed et al., 2024).

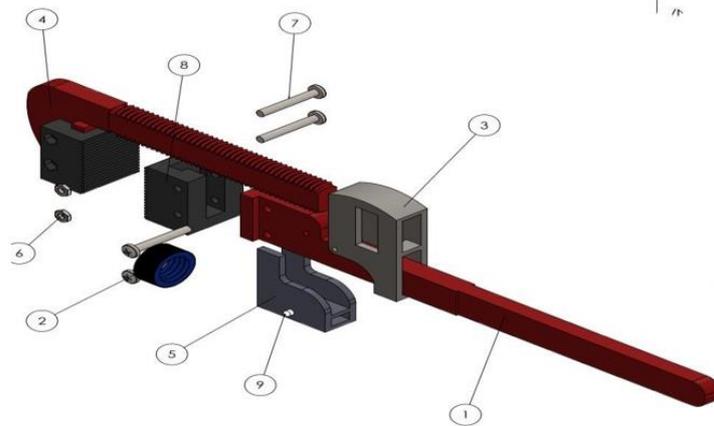
In the 21st century, the evolution of pipe wrenches includes features like aluminum or alloy handles for reduced weight and increased durability. Precision machining and advanced manufacturing processes have enhanced overall quality, making these tools indispensable in various settings, including oil and gas operations where secure gripping and turning of pipes are essential (Konda, 2020).



**Figure 1a:** Isometric view of the designed pipe wrench



**Figure 1 b:** Side view of the pipe wrench



**Figure 2:** Exploded view of the designed pipe wrench showing part list

This research aims to redesign the pipe wrench to enhance functionality, addressing limitations identified in grip strength and efficiency from recent studies affecting safety and work quality in oil field servicing companies (Patel, 2018; Brown et al., 2020). Computational modeling and simulation using SolidWorks and ANSYS were used for topology optimization, as studies indicate their crucial role in optimizing mechanical tools like pipe wrenches (Peter, 2009).

Previous research, by Sawa (2012) explored the impact of scattered bolt preload on the sealing performance of pipe flange connections. Gasket integration significantly improved sealing performance under external bending moment and internal pressure. Nielson, (2009) focused on the development of a pneumatic impulse wrench, emphasizing the importance of ergonomics and safety in pipe wrench design optimization. Szemanek and Hamilton (2022) evaluated pipe flange connection assembly efficiencies using common tools and patterns. While Kumar (2023) developed multiple adjustable wrenches, Sughan et al., 2024 worked on design and fabrication of an adjustable wrench using a disposal chain. These

studies highlighted the continuous efforts to refine pipe wrenches and address specific industry needs.

This research therefore focuses on the optimization of pipe wrenches used in oil field servicing, recognizing the pivotal role these tools play in the efficiency and safety of oil and gas operations. The research encompasses the redesigning and finite element analysis of pipe wrenches, using SolidWorks software and ANSYS, to achieve topology optimization and ensure structural integrity of pipe wrenches.

## Materials and Method

### Design Concept

The redesign of pipe wrench requires a critical analysis of existing designs and their limitations and the incorporation of new design concepts. SolidWorks software and ANSYS were used for the design drawing and to achieve topology optimization and ensure structural integrity of the designed pipe wrenches. Implementing this concept leads to the design of a pipe wrench that is safer and more efficient, enhancing productivity in various industries. The Isometric and side views of the design drawing of pipe wrench are presented in Figure 1 a and b while Figure 2 shows the exploded

view of the design. The part list of the designed pipe wrench is presented in Table 1.

### Material Selection Criteria

The material selection process for the pipe wrench

maintains alignment and contributes to the overall durability of the wrench. The sliding jaw, crucial for gripping, demands high-tensile alloy steels for durability and longevity in challenging industrial conditions.

**Table 1:** Components of a pipe wrench (See Figure 2)

S/N	COMPONENTS	NUMBER
1	Fixed jaw	1
2	Adjustable nut	1
3	Nut housing	1
4	Sliding jaw	2
5	LED case	1
6	Nut	4
7	Screw	4
8	Replaceable jaw	2
9	LED	3

design is critical for ensuring reliability and longevity. High tensile strength, durability, and corrosion resistance are key factors, given the demanding mechanical forces in wrench operation and exposure to harsh industrial conditions. Careful evaluation of material weight is conducted to maintain an ergonomic design for user comfort. Appropriate hardness is sought to prevent wear, and considerations for surface friction aim to optimize gripping performance without causing damage. Cost efficiency is pivotal, ensuring economic viability without compromising essential properties. Machinability contributes to streamlined manufacturing, while thermal stability is crucial for withstanding temperature variations during use. Environmental impact, including recyclability and sustainability, aligns with contemporary standards. Ergonomic properties of materials enhance user comfort and reduce fatigue. These ergonomic considerations include; weight reduction and distribution while maintaining its strength and durability, grip size and shape, incorporation of LED. For the LED integration, materials must exhibit electrical insulating properties for safe operation. The material selection process balances functional, manufacturing, and user-centric needs to create an optimized and resilient pipe wrench.

### Brief Discussion on the Redesigned Pipe Wrench

The implementation of the redesigned pipe wrench involves a process guided by well-defined criteria, aiming to enhance efficiency and safety in oil field operations. The design includes a modular fixed jaw made of alloy steel, featuring an interchangeable configuration for versatile pipe gripping. The adjusting nuts allow rapid and secure adjustments, accommodating pipes of various diameters with a locking mechanism for user safety. The jaw housing, typically crafted from durable materials,

The propelling mechanism screw is made of hardened steel for enduring strength and seamless adjustments. Replaceable jaws offer adaptability with options like hard rubber for surface protection and stainless steel for durability in diverse applications. This dual-material, replaceable jaw system caters to varied operational needs, allowing swift switches for different tasks. The design emphasizes user flexibility with modular and quick-change features, tailored to diverse scenarios in the oil field servicing industry. The LED light case is innovatively integrated, enhancing visibility in low-light environments for precise and safe wrench operation. The LED is to be powered by a CR2032 coin battery. The CR2032 coin cell battery is a compact, widely available, and cost-effective option suitable for low-power applications like LED lights. Its 3-volt output, ease of integration, and extended operational duration make it a practical choice for applications requiring a small, efficient power source. The integrated LED light addresses operational challenges, strategically illuminating the work area for improved efficiency and safety. Topology optimization can result in significant improvements in the performance of pipe wrenches and the safety of oilfield operations. The theoretical basis for topology optimization draws on various optimization algorithms, mathematical modelling techniques, and computational methods. Multi-scale topology optimization, additive manufacturing, and the development of new optimization algorithms are some of the recent advances in the oil servicing field.

### Design Analysis of Some Components of the Pipe wrench

#### Design Criteria and Load Selection:

In designing the pipe wrench, the average working condition indicates that the maximum force applied during regular use is expected to be 450 N (Kumar, 2023). To account for unforeseen circumstances and ensure a safety margin, a load of 900 N is chosen for the topology optimization testing. This choice aligns with industry practices and standards to design tools that not only meet typical usage conditions but also provide robustness in the face of unexpected forces, as given by Sukan *et al.*, 2024.

#### Safety Margin Calculation:

The safety margin calculated from Equation 1, as given by Sukan *et al.* (2024), is the ratio of the chosen load (900 N) to the average working force (450 N). This provides a quantifiable measure of how much the design exceeds typical working conditions.

$$\begin{aligned} \text{Safety margin} &= \frac{\text{Chosen Load}}{\text{Average working load}} \quad (1) \\ &= \frac{900}{450} \\ &= 2 \end{aligned}$$

The safety margin of 2 signifies that the chosen load is twice the expected force during average working conditions, reinforcing the design's resilience and ability to handle variations in applied forces.

#### Determination of Torque applied on the Pipe Wrench

The applied torque on the pipe wrench handle is given in Equation 2, according to Khurmi and Gupta (2005)

$$\tau = F \times L \quad (2)$$

where: F is the force applied to the handle to generate torque

$\tau$  is the torque generated due to applied force

L is the length of the handle

#### Determination of Coefficient of Friction

The coefficient of friction  $\mu$  of the pipe wrench was determined from Equation 3, according to Khurmi and Gupta (2005).

$$\mu = \frac{F_f}{F_n} \quad (3)$$

where:

$\mu$  is the coefficient of friction

$F_f$  is the frictional force which is required to slide or move the pipe

$F_n$  is the normal force applied which is perpendicular to the pipe surface

#### Stress Determination

Bending stress ( $\sigma$ ) imposed on the pipe wrench was calculated using Equation 4, according to Khurmi and Gupta (2005)

$$\sigma = \frac{32 \times F \times L}{\pi d^3} \quad (4)$$

where F is the force applied, L is the length of the handle and d is the diameter of the handle.

Torsional stress ( $\tau$ ) can be determined from Equation 5, according to Khurmi and Gupta (2005)

$$\tau = \frac{16 \times T}{\pi d^3} \quad (5)$$

where T is the torque applied.

#### Jaw Design

Jaw contact area (A) was determined from Equation 6 and jaw pressure was estimated using Equation 7, respectively, according to Khurmi and Gupta (2005)

$$\text{Jaw contact area } A = \pi \times d \times w \quad (6)$$

where d is the pipe diameter and w is the width of the jaw.

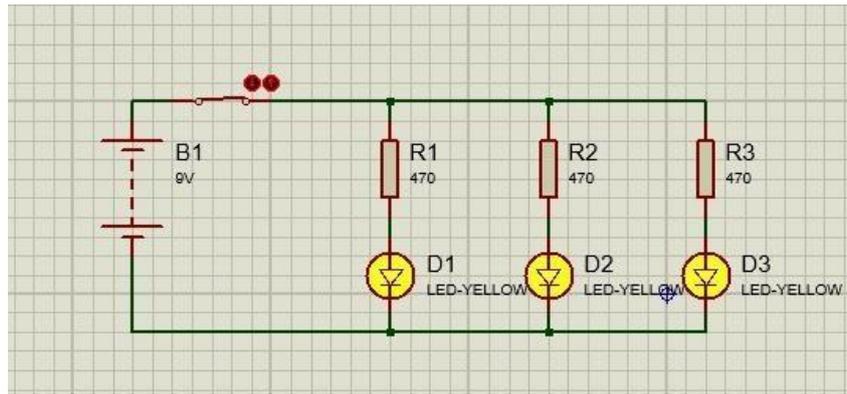
$$\text{Jaw pressure (P): } P = F / A \quad (7)$$

where F is the force applied.

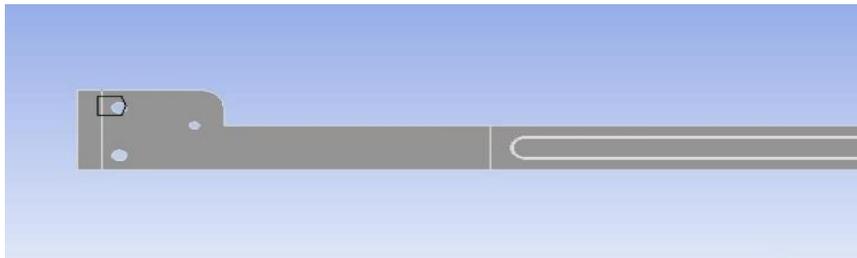
#### Standard Modelling on the Wrench

In a static structural analysis setup, a fixed support was subjected to a maximum applied load of 900 N. The fixed support condition implies that the structure is restrained against translation and rotation, emulating a stable attachment to a rigid base. This restraint ensures the structure remains fixed, allowing for a realistic representation of real-world scenarios. The applied load was to test the impact of external forces, enabling an assessment of the structure's response. This methodology focuses on employing topology optimization to redesign a pipe wrench for mass reduction while preserving material strength. A stress performance test, conducted with a doubled force of 900 N to simulate real-world handling conditions, validates the structural integrity.

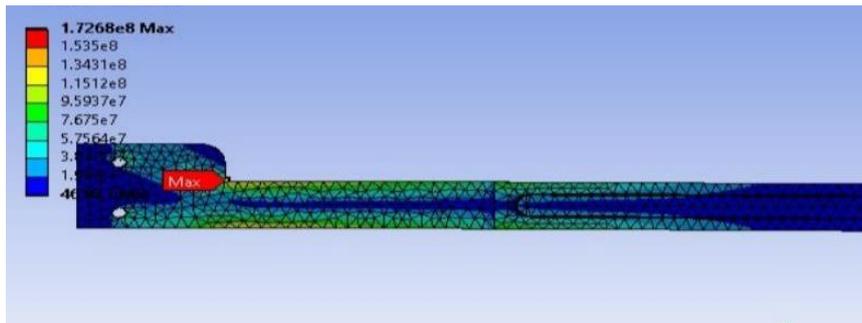
Following the optimization process, the redesigned pipe wrench was subjected to static-structural analysis to assess its structural integrity under varying working conditions. Torque tests were conducted across a range from 30 N/m to 70 N/m, providing a thorough evaluation of the wrench's performance. This analysis ensures the reliability of the optimized design and verifies its suitability for diverse operational scenarios, reinforcing the commitment to engineering excellence in the design of the enhanced pipe wrench.



**Figure 3:** LED light Connection for the Redesigned Wrench using Proteus



**Figure 4:** Static structural analysis with fixed support under 900 N loading condition



**Figure 5:** Static Structural Analysis with Equivalent Stress

In the design of the pipe wrench, Proteus software played a pivotal role in the integration of the LED light circuit. It was used to create a virtual prototype of the LED circuit, allowing visualization and simulation of its behaviour in a digital environment. This step was crucial for assessing the functionality and efficiency of the LED light before any physical implementation, helping to identify and address potential issues in the circuit design.

Proteus facilitated the modelling of the LED and associated components, ensuring an accurate representation of the circuit. Through real-time testing capabilities, the software was deployed in analysing the LED circuit's performance under different conditions, such as varying voltages or resistances. This capability was instrumental in fine-tuning the design, ensuring that the LED light operated optimally in the context of the pipe wrench. LED light Connection for the Redesigned Wrench using Proteus is presented in Figure 3.

## Results and Discussion

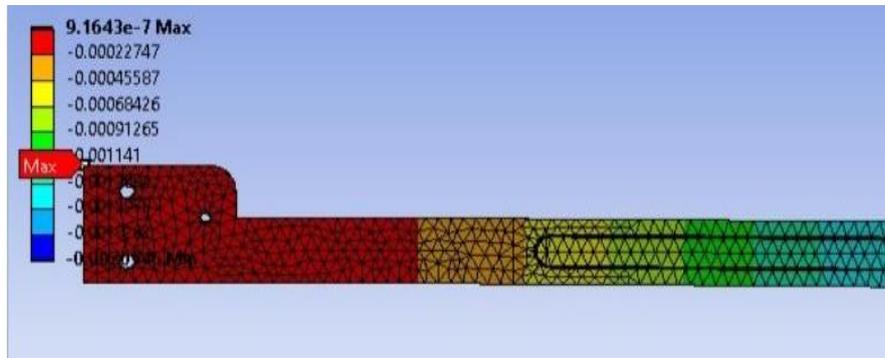
### Static Structural Analysis

In the static structural analysis as shown in Figure 4, a fixed support was subjected to a maximum load of 900 N to simulate real-world scenarios effectively. This fixed support condition ensured the stability of the structure by restraining translation and rotation, mirroring its attachment to a rigid base. By applying this load, it is intended to understand the structure's response to external forces and evaluate its integrity and performance. The obtained results, including equivalent stress and directional deformation, provided insights into potential areas of concern or optimization, guiding further design refinements for enhanced structural robustness and reliability.

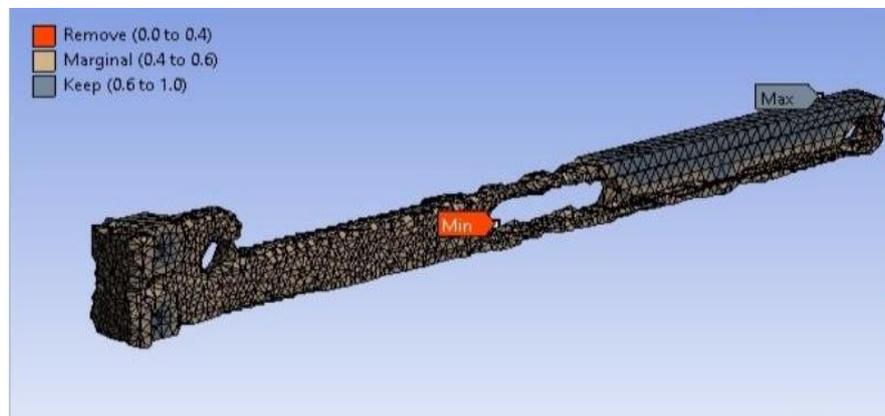
A crucial concept in structural analysis is equivalent stress which simplifies the state at a point in a structure into a single scalar value. This approach involves combining different stress components, such as normal and shear stresses, for easier evaluation and comparison across structural

elements as shown in Figure 5. Results, including equivalent stress and directional deformation, were analyzed to evaluate structural integrity and performance. The combination of fixed support

In the design optimization phase, post-load simulations, spatial stress distribution and directional displacement, were evaluated using advanced analytical tools. Specific attention was



**Figure 6:** Static Structural Analysis for Directional Deformation



**Figure 7:** Structural Optimization showing the Topology Density

constraints and applied load is a critical aspect of the analysis, contributing to a comprehensive understanding of the structure's behavior under specific conditions.

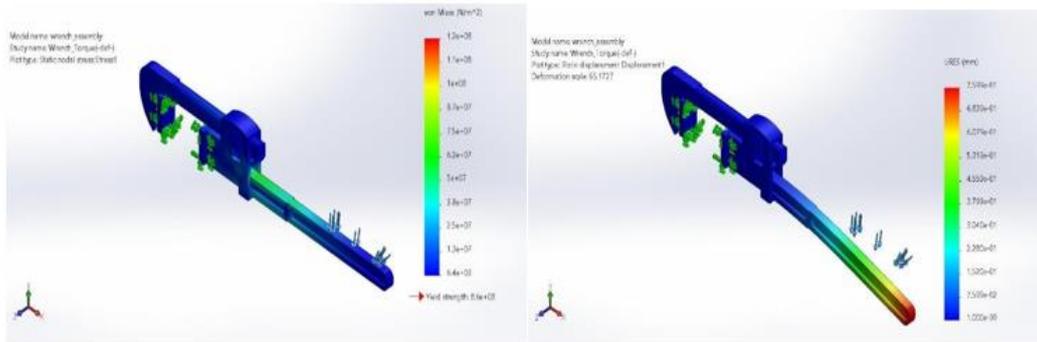
Evaluation of stress distribution in a pipe wrench component was carried out. Using a color-coded visualization technique, stress gradients were illustrated, ranging from vibrant red (indicating peak stress concentration) to cooler shades of blue (reflecting minimal stress areas). This detailed representation allows for a nuanced understanding of stress dispersion, highlighting critical points in red that demand attention and less stressed regions in blue. The visualization not only clarifies stress magnitude and distribution but also aids in making informed design modifications or reinforcements for optimal performance and longevity of the component.

With load applied to the pipe wrench, a detailed stress distribution analysis was conducted, followed by an examination of directional deformation, providing information on its structural behavior as shown in Figure 6.

given to the handle section due to its reduced stress attributes. Emphasizing material efficiency and structural robustness, a targeted mass reduction strategy, employing finite element analysis. This resulted in a 10% reduction of material mass in the handle segment. This approach reflects a design optimization, demonstrating a harmonious blend of engineering expertise and computational techniques to achieve an optimal balance between material utilization and mechanical performance as revealed in Figure 7.

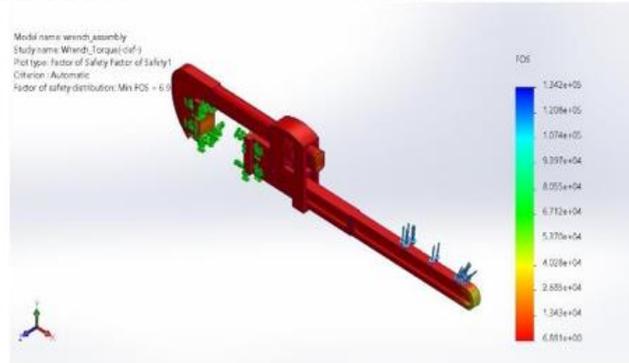
### Static Structural Analysis for Torquing

The CAD model of the optimized pipe wrench was subjected to stress analysis to assess the viability of the conceptual design for aiding production. The study included torquing, stress variation and factor of safety analyses as key components. The results of stress analysis of the optimized pipe wrench for 30 N/m, 40 N/m, 50 N/m, and 60 N/m showing the various torque stresses, torque displacements, and factors of safety are presented in Figures 8, 9, 10 and 11 respectively.



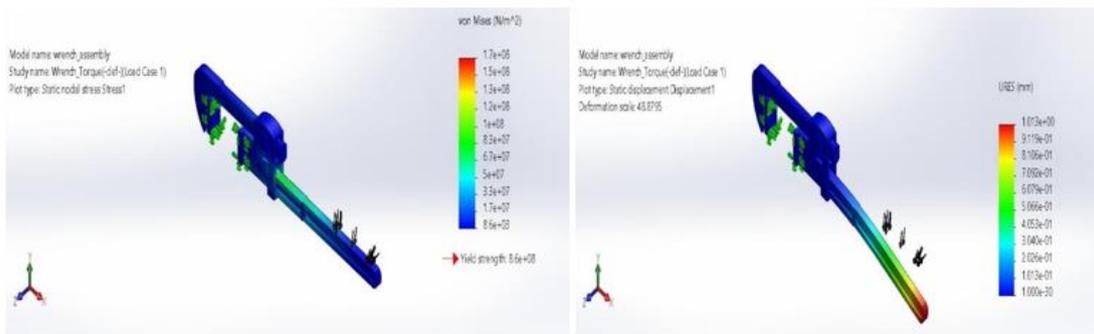
**A. Torque Stress (30 N/m)**

**B. Torque Displacement**



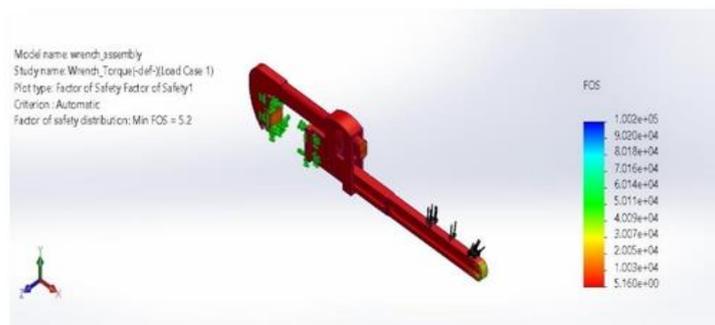
**C. Torque Factor of Safety**

**Figure 8:** Results of Optimized CAD Model of Pipe Wrench under a condition of 30 N/m stress analysis.



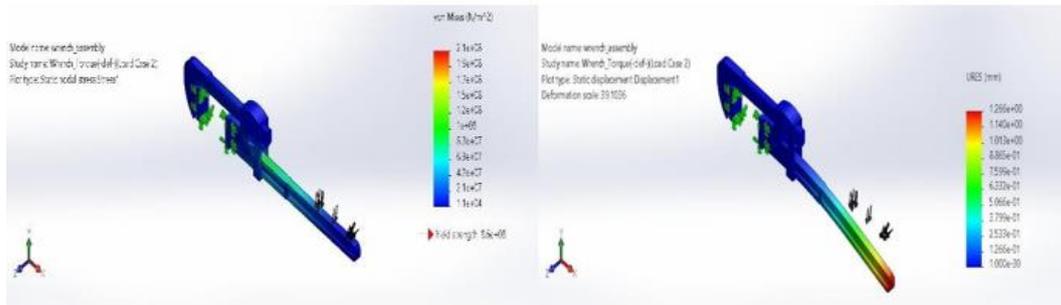
**A. Torque Stress (40 N/m)**

**B. Torque Displacement**



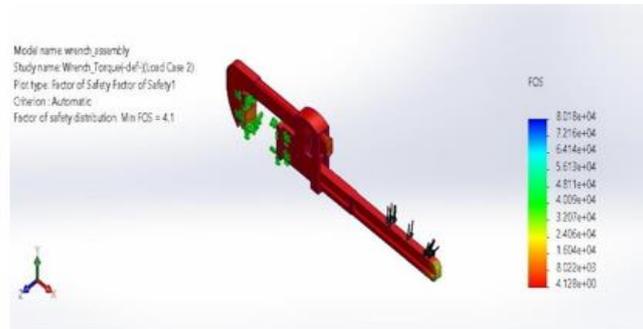
**C. Torque Factor of Safety**

**Figure 9:** Results of Optimized CAD Model of Pipe Wrench under a Condition of 40 N/m Stress Analysis



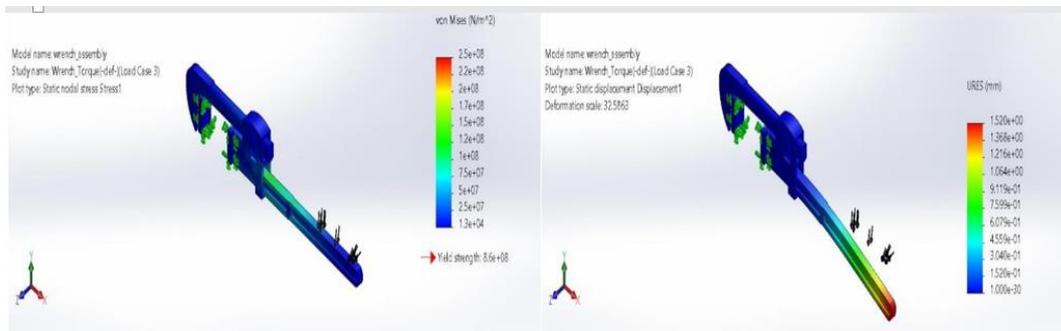
**A. Torque Stress (50 N/m)**

**B. Torque Displacement**



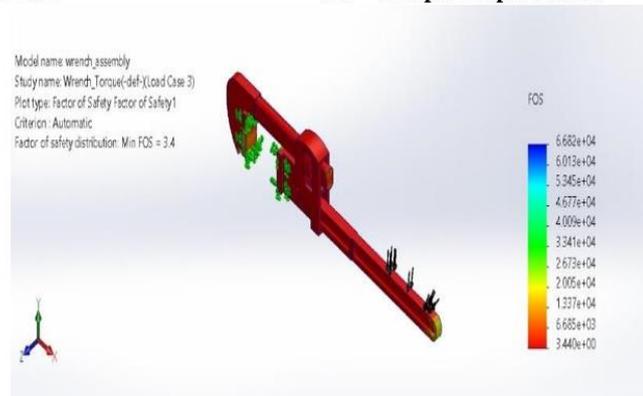
**C. Torque Factor of Safety**

**Figure 10:** Results of optimized CAD Model of pipe wrench under a condition of 40 N/m stress Analysis



**A. Torque Stress for 60 N/m**

**B. Torque Displacement**



**C. Torque factor of safety**

**Figure 11:** Results of optimized CAD Model of pipe wrench under a condition of 60 N/m stress Analysis

In the static structural torque tests, the optimized pipe wrench demonstrated resilience across different torque levels. At 30 N/m, the wrench withstood a maximum torque stress of  $1.2e^8$  N/m, displaying minimal displacement  $7.599e^{-01}$  mm and a factor of safety  $6.881e^{+00}$ . Similarly, at 40 N/m, the wrench endured a maximum torque stress of  $1.7e^8$  N/m with a slight displacement  $1.013e^{+00}$  mm and a substantial factor of safety  $5.160e^{+00}$ . The performance remained robust at 50 N/m, handling a maximum torque stress of  $2.1e^8$  N/m, and maintaining its displacement  $1.266e^{+00}$  mm with an elevated factor of safety  $4.128e^{+00}$ . At 60 N/m, the wrench showcased resilience with a maximum torque stress of  $2.5e^8$  N/m, minimal displacement  $1.520e^{+00}$  mm, and a noteworthy factor of safety  $3.440e^{+00}$ . Post-torque application shows improved stress management profile, affirming the enhanced structural performance of the redesigned wrench. The consistent reliability across varied torque levels underscores the tool's effectiveness under operational conditions.

### Conclusion

This study presents the redesigned and finite element analysis of a pipe wrench, integrating cutting-edge engineering concepts, ergonomic principles, and advanced functionalities to elevate its performance in the demanding landscape of oil servicing. Leveraging SolidWorks software for the design phase allowed for a careful exploration of every component, ensuring precision and alignment. The subsequent simulation and finite element analysis (FEA) delved into static structural analysis, equivalent stress, topology optimization and safety factors, guaranteeing the structural integrity of critical parts of the device. The inclusion of replaceable jaws, a hallmark of adaptability, was engineered to optimize gripping surfaces while extending the tool's lifespan. The redesigned handle topology addresses user comfort and safety, geared towards minimizing operator fatigue and reducing the likelihood of accidents. The results of stress analysis of the optimized pipe wrench for 30 N/m, 40 N/m, 50 N/m, and 60 N/m for various torque stresses, torque displacements, and factors of safety carried out indicated an improved stress management profile, therefore affirming the enhanced structural performance of the redesigned wrench. Moreover, the incorporated topology optimization resulted in a 13.5% reduction in material from 0.1406 kg to 0.1215 kg, while preserving the material's inherent strength. The incorporation of LED lighting will not only illuminate workspaces in low-light conditions but also advanced safety standards by enhancing visibility. In essence, the synergy of SolidWorks design, simulation, FEA analysis, and the inclusion of optimized functions, results in a redesigned pipe wrench that goes beyond convention, exemplifying

a fusion of innovation, precision, and a commitment to the well-being and efficiency of workers in the oil servicing industry.

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