Otopro Volume 21 No. 2 May 2026 pages. 69-77
P-ISSN: 1858-411x; E-ISSN: 2685-7863
DOI: 10.26740/otopro.v21n2.p69-77 https://journal.unesa.ac.id/index.php/jo
(This journal accommodates review, experimental, and thinking related to mechanical engineering and its application)

DESIGN OF A LIFTER FOR HORIZONTAL CHAMBER MACHINE IN A LEAF SPRING PRODUCTION LINE: A CASE STUDY AT PT. XYZ

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Abstract - PT. XYZ is an automotive manufacturing company that produces leaf springs. One of the machines used in the leaf spring forming process is a Horizontal Chamber Machine that works by pressing. In its operation, this machine requires a lifter to assist in the transfer of leaf springs and reduce the risk of workplace accidents. The lifter has a frame component that functions as the main structure in supporting the load during the lifting and lowering of the leaf spring. Therefore, it is necessary to design a lifter frame that is safe and capable of withstanding the working load that occurs during the production process. This study aims to design and evaluate the strength of the lifter frame to ensure its safety in operational use. There are three variations of frame designs differentiated by material thickness, namely 10 mm, 12 mm, and 14 mm. The simulation results show that the maximum stress in frame design 1 is 24 MPa, frame design 2 is 16 MPa, and frame design 3 is 12 MPa. The strain values for each design are 0.000066, 0.000048, and 0.000036, while the displacement maximum values are 0.026 mm, 0.016 mm, and 0.016 mm. The safety factors obtained are 11, 15, and 19, respectively. The fatigue life value for all frame designs is $\mathbf{1.001 \times 10^6}$ cycles. Based on these simulation results, frame design 1 is declared to have met the strength and safety criteria required for use in the production process.

Keywords: Finite Element Analysis, Lifter Frame Design, Structural Strength Analysis, Safety Factor, Fatigue Life

1 Introduction

The horizontal chamber machine is manufacturing equipment used in the leaf spring forming process through a pressing method. It utilizes a hydraulic system to generate compressive force, enabling the material to be shaped according to the die contour. The horizontal chamber orientation allows elongated materials to be positioned stably, ensuring high precision and consistency in the forming process.

A lifter is a mechanical device designed to support the process of lifting, lowering, and adjusting the position of leaf springs so that material transfer can take place safely and efficiently. In general, a lifter can be defined as a mechanical system that functions to lift and move materials from one location to another [1]. In addition to functioning as a means of moving materials, lifters also play a role in improving the reliability of the overall lifting system [2]. In their application in the industrial sector, various types of lifters have been developed, such as hydraulic lifters and pneumatic lifters, each of which has its own characteristics and advantages according to the application requirements, load capacity, workspace limitations, and the level of precision required. Pneumatic-based lifters are capable of producing stable, efficient, and controlled vertical movements, and are suitable for material lifting applications in modern industrial environments [3].

A lifter is a device used at PT. XYZ as an aid in the process of lifting materials on a horizontal chamber machine. This process involves industrial robots that perform high-precision material picking and placing activities. However, in actual conditions, the process of lifting and moving materials still relies on human labour, posing a potential hazard to operators. The use of lifters can also reduce ergonomic risks, decrease musculoskeletal complaints, and improve operator safety and comfort [4]. In addition, the application of lifters in automotive production lines can reduce

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operator walking activities and increase valuable work, making work more productive and ergonomic [5].

The lifter is an additional system designed for horizontal chamber machines to assist in the process of picking up and placing materials (pick and place). This system has main components such as brackets, plate connectors, joints, shafts, linear bushings, pneumatics, and frames.

The frame is a component that functions as a support structure for all installed components and as an element that withstands static loads and maintains the stability of the machine [6]. The frame also plays a role in dampening shocks and protecting components that are sensitive to impact [7]. Not only does it function as a support, the frame also plays an important role in withstanding the working loads and vibrations that occur during machine operation, thereby maintaining the structural integrity and stability of the mechanical system as a whole. With its characteristics of strength, rigidity, and resistance to loads, the frame is the main foundation that determines the reliability and performance of a machine.

SS41 material is a low carbon steel with a maximum carbon content of approximately 0.30% which is classified as structural steel and is widely used in engineering components due to its high ductility and ease of forming [8]. In addition, SS41 is known to have sufficient strength for general applications in construction and manufacturing [9]. With these characteristics, SS41 material is suitable for use in various structural components such as machine frames, mounts, and load supports, as it has a balanced combination of mechanical properties between strength, ductility, and ease of workmanship. Therefore, SS41 material was used as the object of study in this research to evaluate the performance of the lifter frame structure against the working load received.

Finite Element Analysis (FEA) is a numerical method used to evaluate structural behaviour under various loading conditions, including stress, strain, displacement, safety factor, and fatigue life [10], [11]. Finite Element Analysis (FEA) is widely used to evaluate structural performance and predict stress distribution in mechanical components [12]. This method enables accurate prediction of structural performance and ensures that the frame design meets strength, safety, and efficiency requirements before manufacturing.

However, in the current operational conditions at PT. XYZ, the material handling process on the horizontal chamber machine is still partially performed manually. This condition poses several problems, including a high risk of workplace accidents, low ergonomic efficiency, and inconsistent material handling during production. In addition, the absence of a dedicated and optimized lifter frame leads to potential instability and safety concerns during operation.

This study introduces a novel approach by designing a dedicated lifter frame for horizontal chamber machine operations in leaf spring production. The design is optimized based on variations in material thickness and evaluated through structural strength, safety factor, and fatigue performance using Finite Element Analysis (FEA).

Based on the above description, this study aims to design and evaluate the strength and safety level of the lifter frame used in horizontal chamber machines. To ensure that the frame design is safe during operation, this study applies the Finite Element Analysis (FEA) method. The analysis results provide an overview of the strength and safety conditions of the frame structure based on the parameters of maximum stress, strain, maximum displacement, safety factor, and fatigue life. In addition, the results of this study are used as a basis for consideration in selecting the most suitable frame design for actual working conditions.

2 Methods

2.1 Research design

Engineering design research, which focuses on the process of designing and developing mechanical systems based on scientific principles and technical analysis. The main objective of this research is to design and simulate a lifter frame on a horizontal chamber machine that functions in the leaf spring production process. This research focuses on the analysis of lifter frames with plate thickness variations of 10 mm, 12 mm, and 14 mm. Finite Element Analysis (FEA) is used to determine the maximum stress, strain, maximum displacement, safety factor, and fatigue life for each frame design.

2.2 Research flow chart

The flowchart diagram of this research is shown in Figure 1.

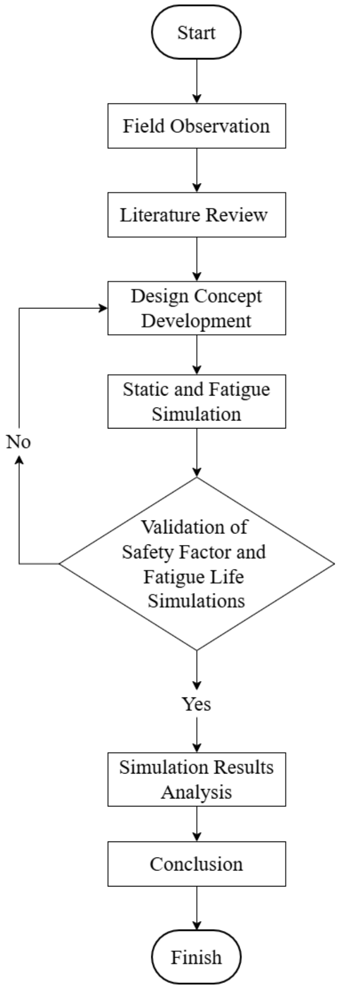

Fig. 1. Research Flow Chart

a. Field observations aim to obtain a realistic picture of the operational conditions of the horizontal chamber machine and identify problems that occur during the process of lifting and moving materials.
b. A literature review was conducted to obtain theoretical foundations and empirical findings related to the research topic, while also examining the methods used in previous studies and understanding technological developments relevant to this field of study.
c. Design concept planning aims to create design alternatives that are in line with system requirements, technical specifications, and existing operational constraints.
d. Simulations were conducted to evaluate the ability of the design structure to withstand workloads. Through these simulations, several mechanical parameters were analysed, including maximum stress, strain, maximum displacement, safety factor, and fatigue life for each frame design.
e. Simulation result validation aims to ensure that the safety factor values obtained meet the safety limits in accordance with the analysis standards used, and that the fatigue life values produced are within the categories specified in the established feasibility criteria.
f. The analysis of simulation results aims to compare the simulation results of each design alternative, so that the design with the most optimal performance based on the analysis parameters used can be determined.
g. Conclusions can be drawn after analysing the maximum stress, strain, maximum displacement, safety factor, and fatigue life.

2.3 Finite element modeling and analysis

The structural simulation of the lifting frame was conducted using the Finite Element Analysis (FEA) method to evaluate its structural strength under static loading and fatigue conditions. A three-dimensional model of the lifting frame was developed based on the actual dimensions of the horizontal chamber machine system. The material used in the simulation was SS41 structural steel, with mechanical properties obtained from an engineering material database.

The meshing process was performed using tetrahedral solid elements, which were adapted to the geometric complexity of the model. To ensure the accuracy of the simulation results, a mesh dependency study was conducted by comparing several mesh sizes until a stable and convergent maximum stress value was achieved. Based on this study, a mesh size of 4 mm was selected, as it provided results that were not significantly affected by further mesh refinement.

In this simulation, boundary conditions were applied in the form of fixed supports at the connection holes of the frame attached to the machine structure, representing rigid connections. The load was applied at the top section of the frame, which serves as the primary support of the lifting system. The total applied load was 843.66 N, corresponding to the mass conversion of 86 kg. This load was derived from the combined weight of components, including the bracket, plate connector, joint, pneumatic system, shaft, linear bushing, nuts, bolts, and washers supported by the frame.

The load was applied vertically downward to represent the actual operating conditions during machine operation. The simulation results analyzed in this study include von Mises stress, strain, displacement, safety factor, and fatigue life. These parameters were used to evaluate the structural performance of the lifting frame and to determine the most optimal and safe design.

2.4 Data analysis

The analysed data was obtained from testing the lifter frame design with three variations in material thickness, namely 10 mm, 12 mm, and 14 mm. The analysis performed on the design included maximum stress, strain, maximum displacement, safety factor, and fatigue life. The results of the data analysis present a comparison of the performance of the lifter frame designs with material thickness variations of 10 mm, 12 mm, and 14 mm tested in this study. Thus, the analysis method used was descriptive quantitative analysis, namely the presentation of data in the form of numerical values that describe the results of the evaluation of the lifter frame structure on the horizontal chamber machine.

3 Results and discussion

3.1 Lifter design on horizontal chamber machine

The design of the lifter on the horizontal chamber machine in this study has the shape and dimensions shown in figure 2 and table 1:

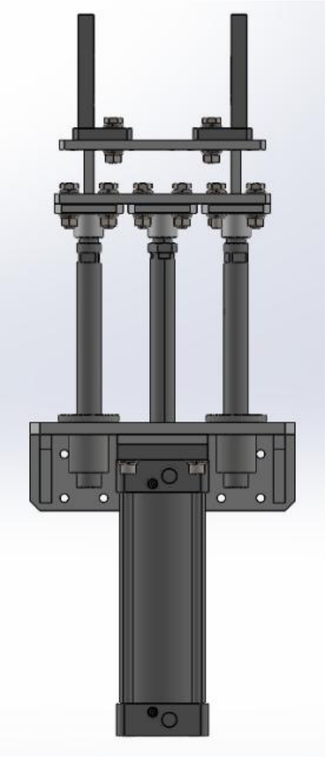

Fig. 2. Lifter design on a horizontal chamber machine

Table 1. Lifter Dimensions on Horizontal Chamber Machine

Dimension	Size
Length	270 mm
Height	736.5 mm
Width	155 mm

Based on table 1 and figure 2, the design and dimensional specifications of the lifter on the horizontal chamber machine are shown. The lifter has a length of 270 mm and a width of 155 mm, with a maximum height of 736.5 mm.

3.2 Lifter frame design on horizontal chamber machine

The lifter frame design on the horizontal chamber machine in this design uses three designs, each distinguished by the thickness of the frame material, namely 10 mm, 12 mm, and 14 mm. This study uses three variations of lifter frame designs on horizontal chamber machines as objects of analysis:

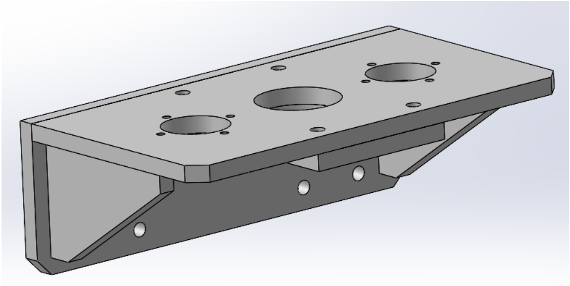

Fig. 3. Frame Design 1

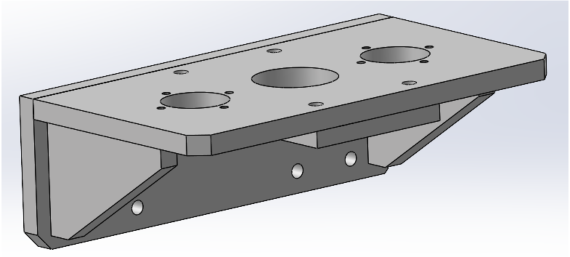

Fig. 4. Frame Design 2

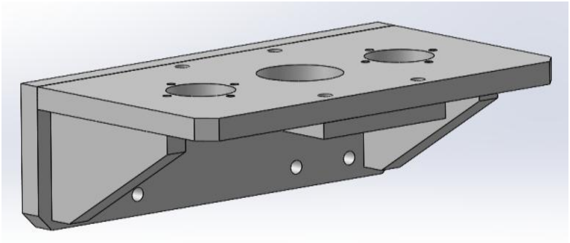

Fig. 5. Frame Design 3

Table 2. Lifter Frame Dimensions on Horizontal Chamber Machine

Dimension	Frame Design 1	Frame Design 2	Frame Design 3
Length	270 mm	270 mm	270 mm
Width	155 mm	157 mm	159 mm
Height	90 mm	90 mm	90 mm
Material Thickness	10 mm	12 mm	14 mm

3.3 Lifter frame material on horizontal chamber machine

The material used in this design is SS41. The selection of this material is based on its properties as low carbon structural steel that has good formability and sufficient mechanical strength to be applied as a lifter frame. Therefore, SS41 material is suitable for use in various structural components such as frames because it has a balanced combination of mechanical properties between strength, ductility, and ease of workmanship. The SS41 material properties specifications are presented in table 3:

Table 3. Material Properties SS41

Properties	Value	Units
Elastic Modulus	200000	MPa
Poisson’s Ratio	0.27	N/A
Shear Modulus	81000	MPa
Mass Density	7850	Kg/m^3
Tensile Strength	400	MPa
Yield Strength	250	MPa

(Source: https://www.matweb.com)

3.4 Selecting fixture points

The fixture point used in this design is set at the connection area between the lifter frame and the horizontal chamber machine. This point is determined at the rear hole of the frame, which functions as the main connection point, so that it can represent the boundary condition in accordance with the actual condition of the frame installation on the lifter. The fixture point can be seen in figure 6:

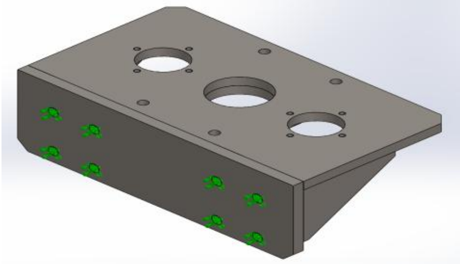

Fig. 6. Lifter Frame Fixture Points

3.5 Application of loads on frame

The load on the lifting frame was applied to the structural components that function as the primary load-bearing elements. This load originates from the mass of components positioned above the frame, as well as from other directly connected elements, such as the pneumatic system and linear bushings within the drive mechanism. The total load applied in the simulation model was 86 kg, equivalent to 843.66 N. This load represents the cumulative mass of components, including the bracket, plate connector, joint, pneumatic system, shaft, linear bushing, nuts, bolts, and washers supported by the frame.

In addition, gravitational effects were incorporated into the simulation with an acceleration value of 9.8 m/s^2. The application of the load on the model is illustrated in Figure 7 below:

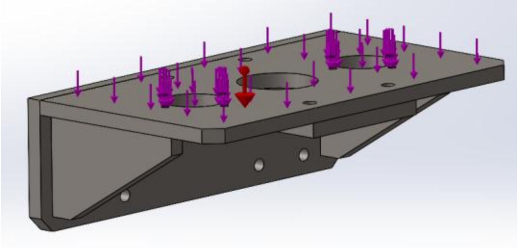

Fig. 7. Load Points on the Lifter Frame

3.6 Simulation results

The results of static and fatigue analysis on frame designs 1, 2, and 3 produced maximum stress, strain, maximum displacement, safety factor, and fatigue life values, which are presented in table 4 below:

Table 4. Simulation Results

Static and Fatigue Analysis	Frame Design 1	Frame Design 2	Frame Design 3
Stress (MPa)	22	16	12
Strain	0.000066	0.000048	0.000036
Displacement (mm)	0.026	0.016	0.011
Safety Factor	11	15	19
Fatigue Life	1×10^6	1×10^6	1×10^6

3.6.1 Stress Simulation

The maximum stress value in frame design 1 shown in figure 8 is 22 MPa, while in frame design 2 shown in figure 9 it is 16 MPa, and in frame design 3 shown in figure 10 it is 12 MPa. If the maximum stress occurring in the structure is still below the yield strength value of the material used, the frame is declared to be guaranteed against plastic failure [13].

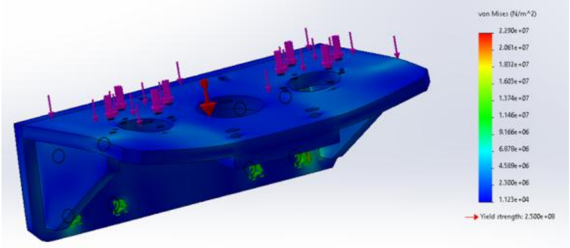

Fig. 8. Stress Simulation Results on Frame Design 1

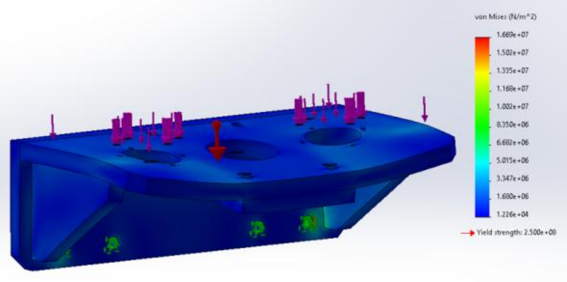

Fig. 9. Stress Simulation Results on Frame Design 2

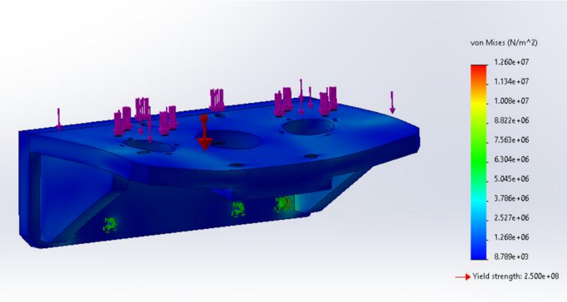

Fig. 10. Stress Simulation Results on Frame Design 3

The simulation results show that frame design 1 has a maximum stress of 22 MPa, frame design 2 of 16 MPa, and frame design 3 of 11 MPa. All these stress values are well below the yield strength of SS41 material, which is 250 MPa, meaning that all three designs meet the required strength criteria. The stress distribution indicates that the maximum values occur at the joints and connections due to load concentration. This phenomenon is consistent with structural mechanics theory, where stress concentrations typically arise in areas with geometric discontinuities. Although Frame Design 3 produces the lowest stresses, all designs remain within the permissible stress limits. This indicates that all three designs are structurally safe. However, the reduction in stress that occurs with increasing thickness is not particularly significant; therefore, material efficiency must be considered when selecting a design.

3.6.2 Strain Simulation

The strain value in frame design 1 shown in figure 11 is 0.000066, while in frame design 2 shown in figure 12, the strain value is 0.000048, and in frame design 3 shown in figure 13, the strain value is 0.000036. The strain values that occur are still within the elastic limit and have not reached the yield strain value (εy), so the frame structure is declared safe from plastic deformation [14].

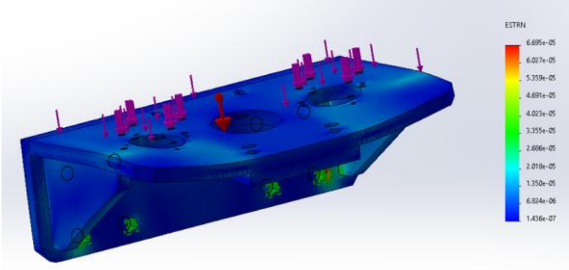

Fig. 11. Strain Simulation Results for Frame Design 1

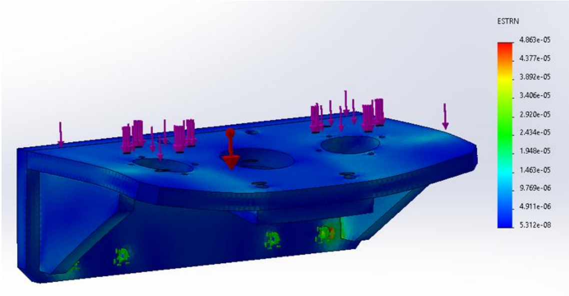

Fig. 12. Strain Simulation Results for Frame Design 2

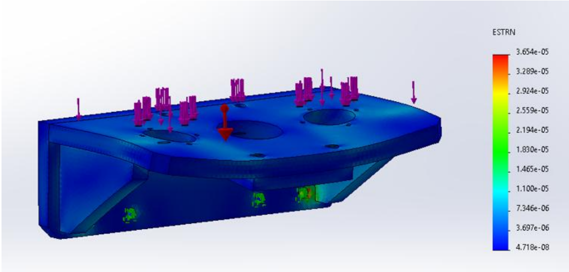

Fig. 13. Strain Simulation Results for Frame Design 3

The test results for frame design 1 produced a strain value of 0.000066, which meets the criteria as it is still far from the material yield strain of 0.00125. The test results for frame design 2 produced a strain value of 0.000048, which meets the criteria as it is still far from the material yield strain of 0.00125. Meanwhile, the test results for frame design 3 obtained a strain value of 0.000036, which greatly meets the criteria as it is still far from the material yield strain of 0.00125.

3.6.3 Maximum displacement simulation

The maximum displacement value in frame design 1 shown in figure 14 is 0.026 mm, while in frame design 2 shown in figure 15, the maximum displacement value obtained is 0.016 mm, and in frame design 3 shown in figure 16, the maximum displacement value obtained is 0.011 mm. Based on the simulation results, the displacement values are well below the permissible limits, so the structure is declared to meet the serviceability requirements or is in a structurally sound condition [15].

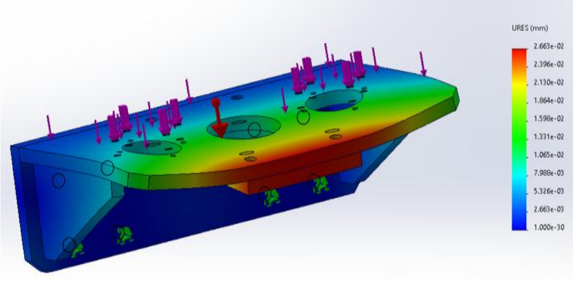

Fig. 14. Displacement Simulation Results for Frame Design 1

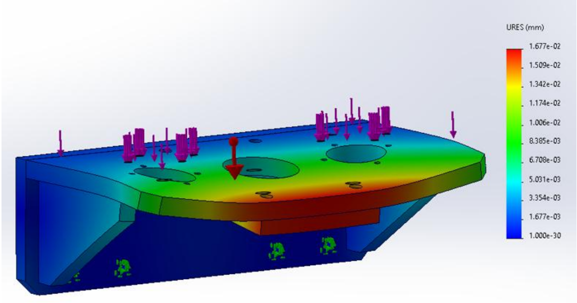

Fig. 15. Displacement Simulation Results for Frame Design 2

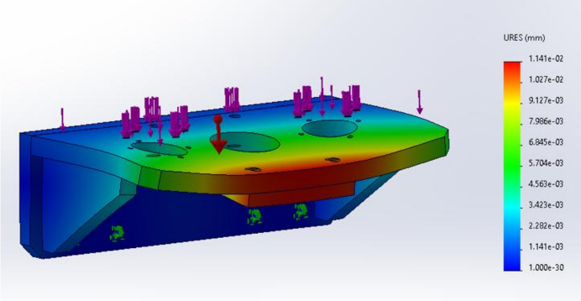

Fig. 16. Displacement Simulation Results for Frame Design 3

The test results for frame design 1 produced a maximum displacement value of 0.026 mm, which meets the criteria as it is still far from the permitted displacement of < 1 mm. Test results for frame design 2 obtained a maximum displacement value of 0.016 mm, which meets the criteria as it is still far from the maximum permissible displacement of < 1 mm. Meanwhile, test results for frame design 3 obtained a maximum displacement value of 0.011 mm, which greatly meets the criteria as it is still far from the permissible displacement of < 1 mm.

3.6.4 Safety factor fimulation

The safety factor value for frame design 1 shown in figure 17 is 11, while for frame design 2 shown in figure 18, the safety factor value is 15, and for frame design 3 shown in figure 19, the safety factor value is 19.

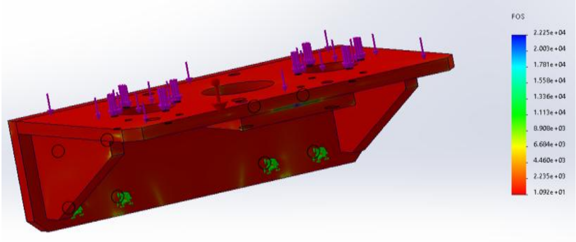

Fig. 17. Safety Factor Simulation Results for Frame Design 1

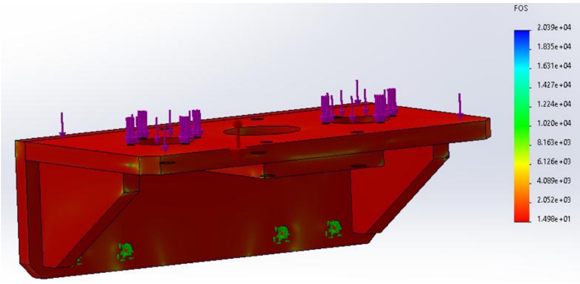

Fig. 18. Safety Factor Simulation Results for Frame Design 2

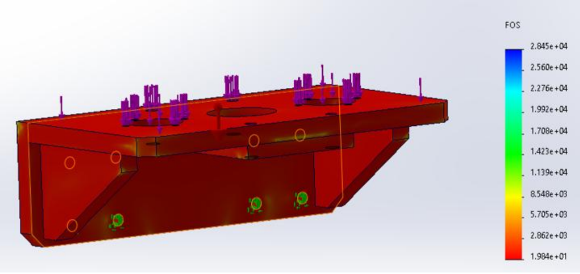

Fig. 19. Safety Factor Simulation Results for Frame Design 3

Based on the test results, frame design 1 produced a safety factor value of 11, frame design 2 produced a value of 15, and frame design 3 produced a value of 19. Referring to the minimum safety factor standard for static load conditions of 4 [16], these frame designs have met the minimum standard criteria for static load safety factors. The relatively high safety factor values obtained in all frame designs indicate that the structures are very safe under the given loading conditions. However, these values also suggest that the designs may be overdesigned. From an engineering perspective, excessively high safety factors can lead to inefficient material usage and increased manufacturing costs. Therefore, frame design 1 is considered more efficient because it already meets the required safety criteria while using less material compared to the other designs.

3.6.5 Fatigue life simulation

Fatigue behaviour is generally evaluated using S–N curves and cyclic loading approaches. The fatigue analysis in this study was carried out under cyclic loading conditions, assuming the presence of fluctuating loads during machine operation. The stress ratio (R) is defined as $R = \sigma(\min) / \sigma(\max)$ and is assumed to be $R = 0$, representing pulsating load conditions. The fatigue life evaluation is based on the assumption of $\geq 1 \times 10^6$ cycles, which corresponds to the high-cycle fatigue regime. The fatigue properties of SS41 material were obtained from standard material databases and commonly used S–N (stress–life) curve references for carbon steel. This data includes key parameters such as ultimate tensile strength, yield strength, and the fatigue strength parameters required for fatigue life prediction. The fatigue limit is used as a benchmark for evaluating the fatigue performance of the structure.

The results of the fatigue life analysis indicate that, for frame designs 1, 2, and 3, all regions of the lifting frame fall within the blue zone, corresponding to a fatigue life of $\geq 1 \times 10^6$ cycles. A fatigue life value of $\geq 1 \times 10^6$ cycles indicates that the structure operates under high-cycle fatigue conditions. This suggests that the working stress is below the endurance limit, and no fatigue failure is expected within the given cycle range [17].

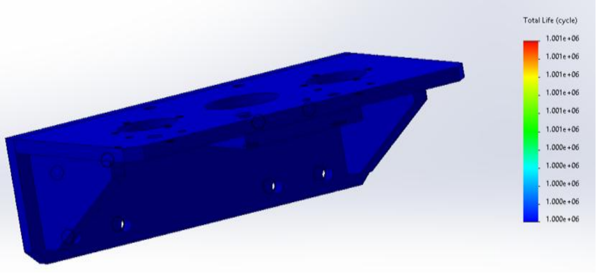

Fig. 20. Fatigue Life Simulation Results for Frame Design 1

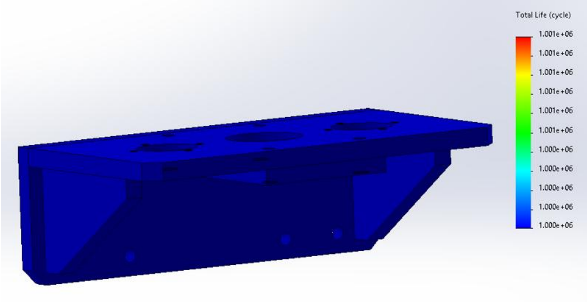

Fig. 21. Fatigue Life Simulation Results for Frame Design 2

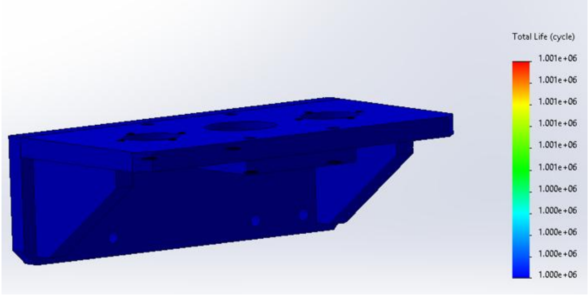

Fig. 22. Fatigue Life Simulation Results for Frame Design 3

Based on the test results, frame designs 1, 2, and 3 produced a fatigue life value of $\geq 1 \times 10^6$ cycles. In the fatigue life category, results of $\geq 1 \times 10^6$ cycles are classified as unlimited fatigue. Therefore, these frame designs have met the unlimited fatigue standard criteria.

4 Conclusion

Based on the results of design research and static and fatigue simulations of the lifter frame on a horizontal chamber machine using SS41 material, it was concluded that:

a. Based on the maximum stress simulation results, the values obtained were 22 MPa for frame design 1, 16 MPa for frame design 2, and 12 MPa for frame design 3. These results indicate that the stress occurring in frame design 1 did not exceed the yield strength of the material, so the design was declared to meet the structural strength requirements.
b. Based on the strain simulation, the design strain values are 0.000066 for frame design 1, 0.000048 for frame design 2, and 0.000036 for frame design 3. Based on a comparison with the material yield strain value of 0.00125, it can be stated that the strain occurring in frame design 1 is still within the elastic limit, thus meeting the criteria for permissible deformation.
c. Based on the simulation results, the maximum displacement of frame design 1 is 0.026 mm, frame design 2 is 0.016 mm, and frame design 3 is 0.011 mm. The simulation results show that the maximum displacement value of frame design 1 is still below the permissible limit (< 1 mm), thus meeting the specified deformation criteria.
d. Based on the simulation, the safety factor for frame design 1 is 11, frame design 2 is 15, and frame design 3 is 19. Based on these results, it can be stated that frame design 1 sufficiently meets the minimum standard criteria for static load safety factor, which is 4.
e. Based on fatigue life simulations on frame design 1, frame design 2, and frame design, a fatigue life value of $\geq 1 \times 10^6$ cycles was obtained. Based on these results, it can be concluded that frame design 1 sufficiently meets the fatigue life criteria, which falls into the infinite fatigue life category.
f. Although frame design 3 exhibits the lowest stress and displacement values, frame design 1 was selected as the optimal design. This is because frame design 1 already meets the required safety criteria, with a safety factor significantly higher than the minimum standard. In addition, it offers advantages in terms of lower material usage, lighter weight, reduced manufacturing cost, and easier fabrication compared to thicker designs. Therefore, frame design 1 is considered the most efficient and practical solution for implementation.

To improve the operational reliability of the lifter frame on horizontal chamber machines, the author offers the following suggestions for further research:

a. Further research is recommended to examine in greater depth the effect of welding techniques on frame design, so that the actual stress distribution on SS41 material can be analysed more accurately.
b. Future researchers are advised to conduct tests on other materials that may have better characteristics for application.

c. In further research, it is recommended to analyse the effect of operating environmental conditions on the performance and service life of the lifter frame, so that the resulting design is more suited to actual field conditions.

Acknowledgements

The author would like to thank PT. XYZ for the permission and support provided during the implementation of this research, including the provision of technical data and supporting facilities. Thanks are also extended to the supervising lecturer and all parties who have provided guidance and assistance so that this research could be completed successfully.

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