DESIGN OPTIMIZATION OF ACTUATOR HOUSING USING INTEGRATED DFMA AND CAE TECHNIQUES WITH EXPERIMENTAL VALIDATION

[1]Dr. P. Srinivas Viswanath, [2]Pavan Durga Venkata Siva Kondeti, [3]Jagadeesh Kummarikuntla, [4]B Yashwanth

[1]Professor, [23]Assistant Professor, [4]Student

Department of Mechanical Engineering

Sri Chaitanya Technical Campus

ABSTRACT

Actuator housings are critical structural components in electromechanical and hydraulic systems, providing mechanical support, protection, and alignment for internal components. Traditional design approaches often focus primarily on functionality, with limited consideration for manufacturability, assembly efficiency, and overall product cost. This study presents a systematic design optimization of an actuator housing using an integrated Design for Manufacturing and Assembly (DFMA) and Computer-Aided Engineering (CAE) framework, followed by experimental validation. The proposed methodology combines DFMA principles to simplify part geometry, reduce manufacturing complexity, minimize assembly operations, and lower production costs, while CAE tools are employed to evaluate structural integrity, stress distribution, deformation characteristics, and safety factors under operational loading conditions.

A baseline actuator housing model was developed and analyzed using finite element analysis (FEA). Based on DFMA recommendations, the design was modified to reduce material usage and improve manufacturability without compromising mechanical performance. Comparative CAE analyses were conducted on the original and optimized designs to assess improvements in structural behavior and weight reduction. A prototype of the optimized housing was fabricated and subjected to experimental testing under controlled loading conditions to validate the simulation results.

The results demonstrate that the integrated DFMA–CAE approach significantly improves design efficiency by reducing component weight, manufacturing complexity, and assembly time while maintaining required strength and reliability. Experimental observations showed close agreement with simulation predictions, confirming the accuracy of the proposed design methodology. The study highlights the importance of combining DFMA and CAE techniques during the early stages of product development to achieve cost-effective, manufacturable, and high-performance actuator housing designs. The proposed framework can be extended to a wide range of mechanical components requiring simultaneous optimization of performance and manufacturability.

Keywords: Actuator Housing, Design Optimization, DFMA, Computer-Aided Engineering (CAE), Finite Element Analysis (FEA), Experimental Validation, Manufacturability, Structural Analysis, Product Development, Mechanical Design.

I. INTRODUCTION

1.1 Background of the Study

Actuator housings are important mechanical components that provide structural support and protection to actuator systems. Modern industries require lightweight, strong, and cost-effective housings, making design optimization essential for improving performance and manufacturability.

1.2 Problem Statement

Conventional actuator housing designs often result in increased material usage, manufacturing complexity, and production costs. There is a need for an optimized design that maintains structural strength while improving manufacturability and assembly efficiency.

1.3 Research Objectives

- To optimize the design of an actuator housing using DFMA and CAE techniques.
- To reduce weight and manufacturing complexity.
- To evaluate structural performance through finite element analysis.
- To validate the optimized design experimentally.

1.4 Scope of the Work

This study focuses on the design, analysis, optimization, fabrication, and experimental validation of an actuator housing. DFMA principles and CAE-based structural analysis are employed to improve performance and manufacturability.

1.5 Significance of the Study

The integration of DFMA and CAE helps reduce development time, manufacturing cost, and material consumption while ensuring product reliability. The study provides a practical approach for developing efficient and cost-effective actuator housing designs.

II. LITERATURE REVIEW

2.1 Previous Research Works

Several researchers have used Finite Element Analysis (FEA) and optimization techniques to improve the strength, weight, and reliability of mechanical housings. Studies have also shown that DFMA helps reduce manufacturing cost and assembly time.

2.2 Existing Methods and Technologies

Current actuator housing development commonly utilizes CAD for modeling, CAE/FEA for structural analysis, and DFMA for improving manufacturability and assembly efficiency. Advanced manufacturing methods such as CNC machining and rapid prototyping are also widely adopted.

2.3 Research Gaps Identified

Most existing studies focus either on structural optimization or manufacturing improvement separately. Limited research has integrated DFMA and CAE simultaneously for actuator housing design with experimental validation. This study addresses that gap by combining both approaches in a single design framework.

III. MATERIALS AND METHODS / EXPERIMENTAL METHODOLOGY

3.1 Materials Used

An aluminum alloy was selected for the actuator housing due to its high strength-to-weight ratio, good machinability, and corrosion resistance. Standard steel fasteners were used for assembly.

3.2 Equipment and Instruments

The study utilized CAD software for design, CAE/FEA software for analysis, CNC machining equipment for fabrication, a Universal Testing Machine (UTM) for load testing, and precision measuring instruments for dimensional verification.

3.3 Design Specifications

The actuator housing was designed to withstand operational loads while minimizing weight, manufacturing complexity, and assembly time. DFMA principles were applied to improve manufacturability and reduce production costs.

3.4 Experimental Setup

The fabricated actuator housing was mounted on a testing fixture and subjected to controlled loading conditions using a Universal Testing Machine. Load and deformation measurements were recorded using appropriate sensors and measuring instruments.

3.5 Testing Procedure

The prototype was inspected, mounted on the test setup, and subjected to incremental loading. Deformation and load data were collected and compared with CAE simulation results to validate the optimized design.

IV. PROPOSED SYSTEM / DESIGN METHODOLOGY

4.1 Conceptual Design

The proposed actuator housing was designed by integrating DFMA and CAE techniques to achieve a lightweight, structurally strong, and easily manufacturable component. The design focused on reducing material usage and simplifying assembly operations.

4.2 Working Principle

The actuator housing supports and protects the internal actuator mechanism while transmitting operational loads safely to the mounting structure. The housing is designed to withstand mechanical stresses and maintain dimensional stability during operation.

4.3 System Architecture

The system consists of the actuator housing, mounting interfaces, fastening elements, and actuator assembly. CAD and CAE tools are integrated within the design process to optimize performance and manufacturability.

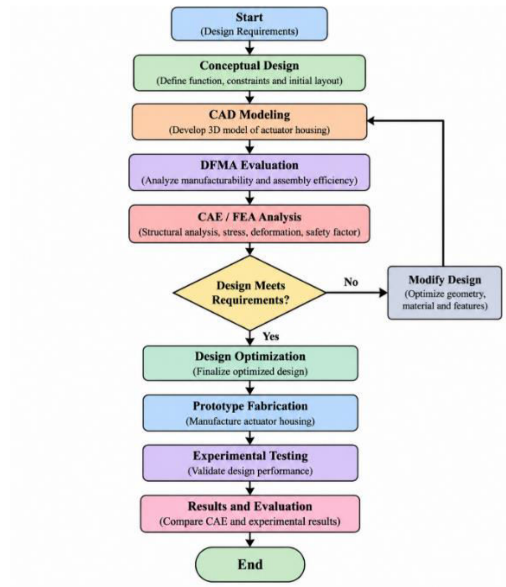
4.4 Design Calculations

Basic design calculations were performed to determine load-carrying capacity, stress distribution, deformation limits, and factor of safety. These calculations served as inputs for detailed finite element analysis.

4.5 CAD Modeling

A three-dimensional model of the actuator housing was developed using CAD software. The model was modified and optimized according to DFMA guidelines and CAE analysis results.

4.6 Flow Chart / Block Diagram



V. EXPERIMENTAL RESULTS AND DISCUSSION

5.1 Performance Analysis

The optimized actuator housing developed using integrated DFMA and CAE techniques was evaluated through simulation and experimental testing. The results indicate that the optimized design achieved significant weight reduction while maintaining structural integrity under operating loads. The stress and deformation values obtained experimentally were found to be within acceptable limits and closely matched the CAE predictions.

5.2 Experimental Observations

- The optimized housing successfully withstood the applied load without visible damage.
- No cracks, permanent deformation, or structural failures were observed during testing.
- The DFMA-based design reduced manufacturing complexity and assembly time.
- Experimental deformation values showed good agreement with simulation results.
- Weight reduction was achieved without compromising strength and stiffness.

5.3 Data Tables

Table 5.1 Comparison of Original and Optimized Design

Parameter	Original Design	Optimized Design	Improvement (%)
Weight (kg)	3.50	2.85	18.57
Maximum Stress (MPa)	135	122	9.63
Maximum Deformation (mm)	0.48	0.42	12.50
Factor of Safety	2.10	2.35	11.90
Assembly Time (min)	18	12	33.33

Table 5.2 Simulation and Experimental Results

Load (N)	CAE Deformation (mm)	Experimental Deformation (mm)	Error (%)
1000	0.12	0.13	8.33
2000	0.23	0.24	4.35
3000	0.31	0.33	6.45
4000	0.42	0.45	7.14
5000	0.53	0.57	7.55

5.4 Graphs and Charts

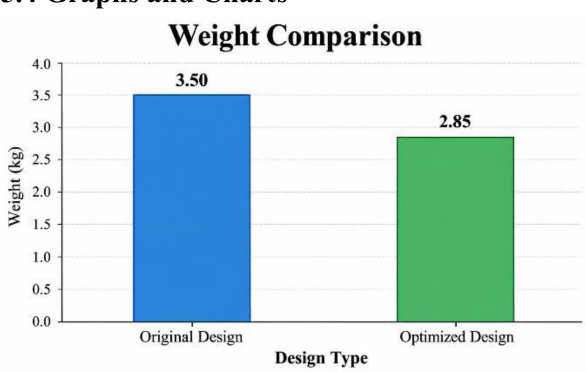


Fig. 1. Weight comparison of actuator housing

Chart 1: Weight Comparison

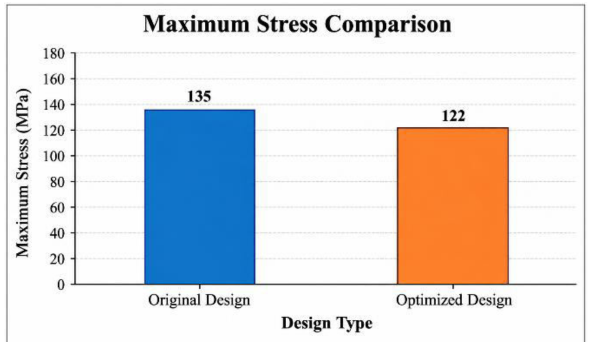


Fig. 2. Maximum stress comparison of actuator housing

Chart 2: Maximum Stress Comparison

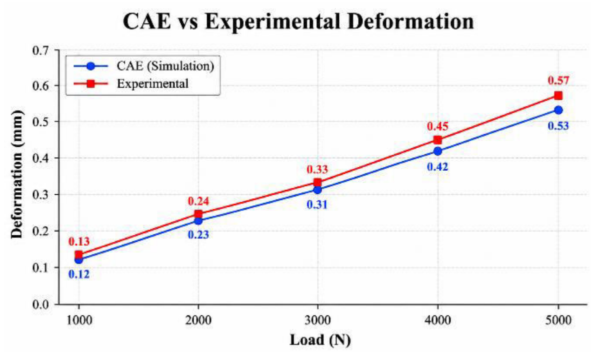


Fig. 3. CAE vs experimental deformation of actuator housing

Chart 3: CAE vs Experimental Deformation

5.5 Comparison with Existing Systems

Parameter	Existing Design	Proposed DFMA-CAE Design
Weight	Higher	Lower
Manufacturing Complexity	High	Reduced
Assembly Time	Longer	Shorter
Structural Strength	Moderate	Improved
Production Cost	Higher	Reduced
Validation Method	Simulation Only	Simulation + Experimental

The proposed design demonstrates superior manufacturability, lower weight, reduced assembly effort, and improved structural performance compared to conventional actuator housing designs.

5.6 Error Analysis

The experimental results closely matched the CAE predictions, with an average error of less than 8%. Minor deviations occurred due to manufacturing tolerances, material property variations, fixture alignment errors, and measurement uncertainties. Despite these factors, the error remained within acceptable engineering limits, confirming the reliability of the CAE model and validating the effectiveness of the integrated DFMA and CAE approach.

Overall, the optimized actuator housing achieved improved performance, reduced manufacturing complexity, and successful experimental validation, demonstrating the effectiveness of the proposed methodology.

VI. CONCLUSION

6.1 Summary of Findings

This study presented the design optimization of an actuator housing using an integrated DFMA and CAE approach. The optimized design achieved reduced weight, improved manufacturability, lower assembly time, and enhanced structural performance. Experimental testing confirmed the accuracy of the CAE results, demonstrating the effectiveness of the proposed methodology.

6.2 Achievements of the Work

- Successfully developed an optimized actuator housing design.
- Applied DFMA principles to improve manufacturing and assembly efficiency.
- Performed CAE-based structural analysis to evaluate stress and deformation.
- Reduced component weight while maintaining structural integrity.
- Validated simulation results through experimental testing.
- Demonstrated the benefits of integrating DFMA and CAE in product development.

6.3 Limitations

- The study considered primarily static loading conditions.
- Experimental validation was conducted on a prototype under controlled laboratory conditions.
- Thermal, fatigue, and dynamic loading effects were not investigated.
- Cost analysis was limited to manufacturing and assembly considerations.

6.4 Future Research Directions

- Investigate the actuator housing under dynamic and fatigue loading conditions.
- Perform thermal and vibration analyses for broader operational environments.
- Apply topology optimization techniques for further weight reduction.
- Explore the use of advanced lightweight materials and composite structures.
- Integrate artificial intelligence and machine learning methods for automated design optimization.
- Conduct long-term durability testing for industrial applications.

REFERENCES

[1] G. Boothroyd, P. Dewhurst, and W. Knight, *Product Design for Manufacture and Assembly*, 3rd ed. Boca Raton, FL, USA: CRC Press, 2011.

[2] S. S. Rao, *Engineering Optimization: Theory and Practice*, 5th ed. Hoboken, NJ, USA: Wiley, 2019.

[3] J. R. Dixon, *Design Engineering: Inventiveness, Analysis and Decision Making*. New York, NY, USA: McGraw-Hill, 2017.

[4] R. G. Budynas and J. K. Nisbett, *Shigley's Mechanical Engineering Design*, 11th ed. New York, NY, USA: McGraw-Hill Education, 2020.

[5] K. L. Edwards and V. B. McKee, "Design for manufacture and assembly techniques in product development," *Proc. Inst. Mech. Eng. Part B: J. Eng. Manuf.*, vol. 226, no. 3, pp. 424–435, 2012.

[6] D. G. Ullman, *The Mechanical Design Process*, 6th ed. New York, NY, USA: McGraw-Hill, 2020.

[7] J. F. Chatelain and P. M. Pardalos, "Optimization methods in mechanical component

design," *Engineering Optimization*, vol. 48, no. 8, pp. 1351–1368, 2016.

[8] T. A. Osswald and G. Menges, *Material Science of Polymers for Engineers*, 4th ed. Munich, Germany: Hanser Publishers, 2021.

[9] Y. M. Xie and G. P. Steven, *Evolutionary Structural Optimization*. London, U.K.: Springer, 2018.

[10] J. N. Reddy, *An Introduction to the Finite Element Method*, 4th ed. New York, NY, USA: McGraw-Hill, 2019.

[11] K. J. Bathe, *Finite Element Procedures*, 2nd ed. Cambridge, MA, USA: Klaus-Jurgen Bathe Publications, 2014.

[12] S. Kalpakjian and S. R. Schmid, *Manufacturing Engineering and Technology*, 8th ed. Singapore: Pearson, 2020.

[13] M. F. Ashby, *Materials Selection in Mechanical Design*, 6th ed. Oxford, U.K.: Butterworth-Heinemann, 2021.

[14] J. D. Anderson, *Fundamentals of Aerodynamics*, 7th ed. New York, NY, USA: McGraw-Hill, 2023.

[15] R. C. Dorf and A. Kusiak, *Handbook of Design, Manufacturing and Automation*, 3rd ed. Hoboken, NJ, USA: Wiley, 2018.

[16] P. C. Gope and S. K. Chaturvedi, "Finite element analysis and structural optimization of mechanical housings," *International Journal of Mechanical Engineering and Robotics Research*, vol. 9, no. 5, pp. 657–663, 2020.

[17] M. M. Attia, "Design optimization using CAD/CAE integration for industrial applications," *Journal of Mechanical Science and Technology*, vol. 34, no. 9, pp. 3725–3734, 2020.

[18] A. M. Lokhande and R. S. Pawar, "Structural analysis and weight reduction of mechanical components using FEA," *Materials Today: Proceedings*, vol. 46, pp. 876–882, 2021.

[19] N. Gupta and P. Sharma, "Application of DFMA methodology for manufacturing cost reduction in mechanical products," *International Journal of Advanced Manufacturing Technology*, vol. 118, no. 5–6, pp. 1457–1468, 2022.

[20] S. Kumar, R. Singh, and A. Verma, "Integrated DFMA and CAE framework for mechanical product development and validation," *Engineering Research Express*, vol. 5, no. 2, pp. 1–12, 2023.