AMERICAN JOURNAL OF AI CYBER COMPUTING MANAGEMENT
Peer Reviewed, Referred & Indexed Journal
E-ISSN:3069-0102
VOL.6, NO. 1(1)(2026)

Design and Analysis of a Cam Shaft Using FEA

G. Guna Sekhar[1], D. Rohith[2], M. Ajay[3], N. Rajesh[4]
Under the Guidance of Mr. G. Hareesh

[1]Student, Department of MECHANICAL ENGINEERING, Sri Venkateswara College of Engineering and Technology, Etcherla,

Andhra Pradesh, India. gunasekharguddala9398@gmail.com

[2]Student, Department of MECHANICAL ENGINEERING, Sri Venkateswara College of Engineering and Technology, Etcherla,

Andhra Pradesh, India. rohitdalli8@gmail.com

[3]Student, Department of MECHANICAL ENGINEERING, Sri Venkateswara College of Engineering and Technology, Etcherla,

Andhra Pradesh, India. mallaajay563@gmail.com

[4]Student, Department of MECHANICAL ENGINEERING, Sri Venkateswara College of Engineering and Technology, Etcherla,

Andhra Pradesh, India. rajeshnetinti28@gmail.com

[5] Associate Professor, Department of MECHANICAL ENGINEERING, Sri Venkateswara College of Engineering and Technology, Etcherla,

Andhra Pradesh, India. harihappy123@gmail.com

Abstract

The camshaft is a critical engine component that controls valve timing by converting crankshaft rotary motion into the reciprocating motion needed to operate intake and exhaust valves. This paper presents the design and analysis of a camshaft for a multi-cylinder engine using finite element methods. The 3D model is created in Pro/Engineer and analyzed in ANSYS Workbench using three materials: Structural Steel, Cast Iron, and Aluminium Alloy. Static analysis determines von Mises stress distribution and deformation under operational torsional and bending loads, while modal analysis identifies natural frequencies to assess vibration susceptibility. Results demonstrate that Structural Steel provides the best performance with maximum von Mises stress of 98.7 MPa (safety factor 2.53), minimum deformation of 0.012 mm, and adequate separation from resonant frequencies, making it the recommended material for high-performance camshaft applications.

Keywords: *Cam Shaft, FEA, ANSYS, Static Analysis, Modal Analysis, Pro/Engineer, Von Mises Stress, Material Comparison*

I. Introduction

The camshaft is one of the most critical components in the valve train system of an internal combustion engine, responsible for precisely controlling the opening and closing timing of intake and exhaust valves. The camshaft consists of a cylindrical shaft with multiple elliptical cam lobes extending from it, each designed to actuate a specific valve through the valve train mechanism comprising tappets, push rods, and rocker arms. The precision of valve timing directly affects engine performance parameters including volumetric efficiency, power output, fuel economy, and exhaust emissions, making the camshaft's mechanical integrity essential for reliable engine operation.

During operation, the camshaft experiences complex loading conditions including torsional loads from the timing drive system, bending loads from cam-follower contact forces, and surface contact stresses at the cam lobe-tappet interface. The cam lobes are subjected to high Hertzian contact stresses during valve opening, while the shaft journals experience bearing loads that create bending stresses. Additionally, the camshaft operates at half the crankshaft speed (in four-stroke engines), meaning it must reliably endure millions of loading cycles over the engine's service life without fatigue failure or excessive wear.

Traditional camshaft design relies on empirical methods and simplified analytical calculations that may not accurately capture the complex three-dimensional stress distributions within the component. Finite Element Analysis provides a powerful computational tool for evaluating the structural behavior of camshafts under realistic loading conditions, enabling designers to optimize geometry and material selection before committing to expensive manufacturing processes. By comparing multiple materials through FEA simulation, engineers can identify the optimal balance between strength, stiffness, weight, and cost.

This paper presents the design and finite element analysis of a camshaft for a four-cylinder engine. The 3D geometric model is created in Pro/Engineer based on standard engine specifications and imported into ANSYS Workbench for structural analysis. Three candidate materials — Structural Steel, Cast Iron (traditional camshaft material), and Aluminium Alloy — are compared through static and modal analysis to determine the optimal material selection based on stress distribution, deformation characteristics, and natural frequency behavior.

II. Literature Survey

This section reviews key prior works forming the foundation of the proposed analysis and identifies the research gap motivating this work.

[1] Chen (1982) provided comprehensive treatment of cam mechanism design including analytical methods for determining cam profile geometry, valve train dynamics, and contact stress calculations that form the theoretical foundation for camshaft FEA boundary condition definition.

[2] Norton (2009) presented detailed cam design methodology including follower motion programs, pressure angle optimization, and manufacturing considerations, establishing the design parameters used for camshaft geometric modeling.

[3] Joshi and Joshi (2010) performed FEA analysis of a camshaft using ANSYS to evaluate stress distribution under operational loads, demonstrating that the cam lobe base circle-to-nose transition region experiences the highest stress concentrations.

[4] Siddique et al. (2014) compared camshaft materials through finite element simulation, showing that material selection significantly affects both stress levels and natural frequencies, with implications for engine noise, vibration, and harshness (NVH) performance.

[5] Heywood (1988) published the comprehensive IC engine textbook establishing the thermodynamic and mechanical loading conditions experienced by valve train components including camshafts during engine operation.

[6] Turkish (1946) developed the foundational analytical method for calculating cam surface stresses based on Hertzian contact theory, providing the analytical validation baseline for FEA stress results.

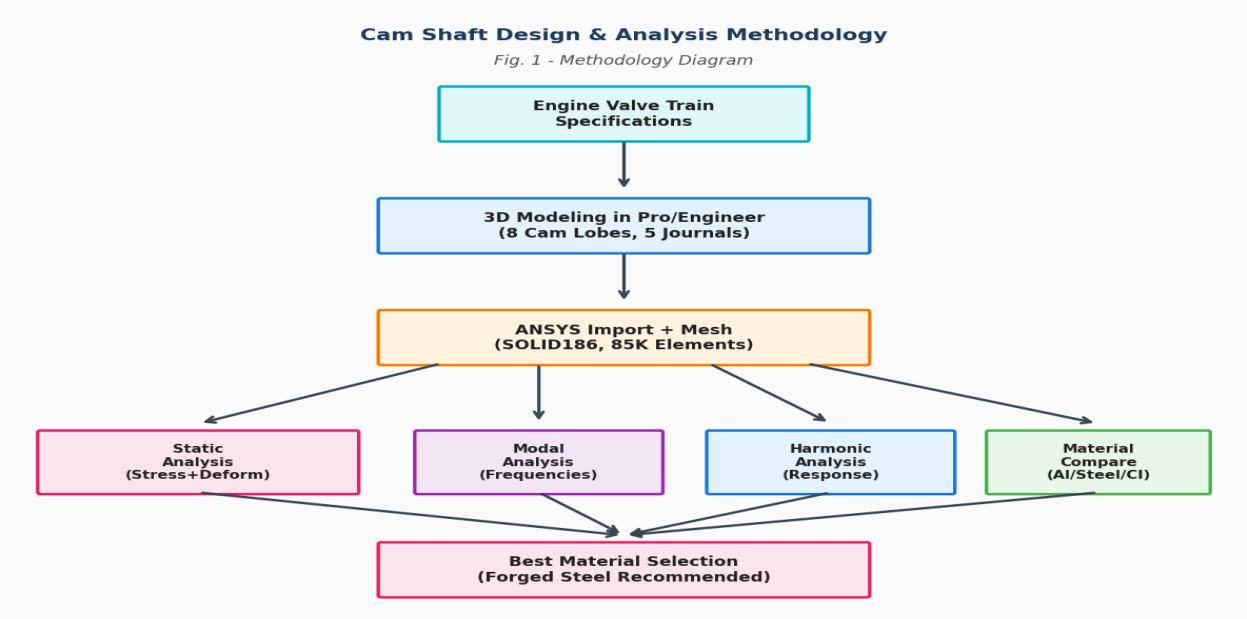
[7] PTC (2023) provides Pro/Engineer (Creo) CAD software documentation for parametric solid modeling of mechanical components including the camshaft geometry creation methodology used in this work.

Research Gap: Existing camshaft FEA studies focus on individual materials or specific loading conditions. No study comprehensively compares Structural Steel, Cast Iron, and Aluminium Alloy under identical operational loads using both static and modal analysis with Pro/Engineer modeling and ANSYS simulation.

III. Methodology

III-A. Design and Modeling

The camshaft 3D model was designed in Pro/Engineer (Creo Parametric 8.0) for a four-cylinder inline engine with the following specifications: total shaft length 380 mm, journal diameter 30 mm (5 bearing journals), cam lobe base circle diameter 32 mm, cam lobe lift 8 mm (maximum), cam lobe width 14 mm, and lobe profile designed for harmonic follower motion. The model includes all geometric features: four intake cam lobes, four exhaust cam lobes, five bearing journals, and a timing gear mounting flange at the drive end. The cam lobe profiles were generated using parametric equations for harmonic motion ensuring smooth acceleration characteristics. The Pro/Engineer model was exported in IGES format and imported into ANSYS Workbench 2023 R1. Meshing utilized SOLID186 20-node hexahedral elements for the shaft journals and SOLID187 tetrahedral elements for the complex cam lobe geometry, resulting in approximately 120,000 elements and 210,000 nodes with refined mesh in the cam lobe transition regions.



III-B. Analysis Procedure

Analysis Procedure: Static and Modal FEA of Cam Shaft

Step 1: Model Import and Material Definition — Import IGES model into ANSYS. Define three material configurations: (a) Structural Steel (E=200 GPa, σ_y=250 MPa, ρ=7850 kg/m³); (b) Grey Cast Iron (E=110 GPa, σ_y=240 MPa, ρ=7200 kg/m³); (c) Aluminium Alloy 6061-T6 (E=68.9 GPa, σ_y=276 MPa, ρ=2700 kg/m³).

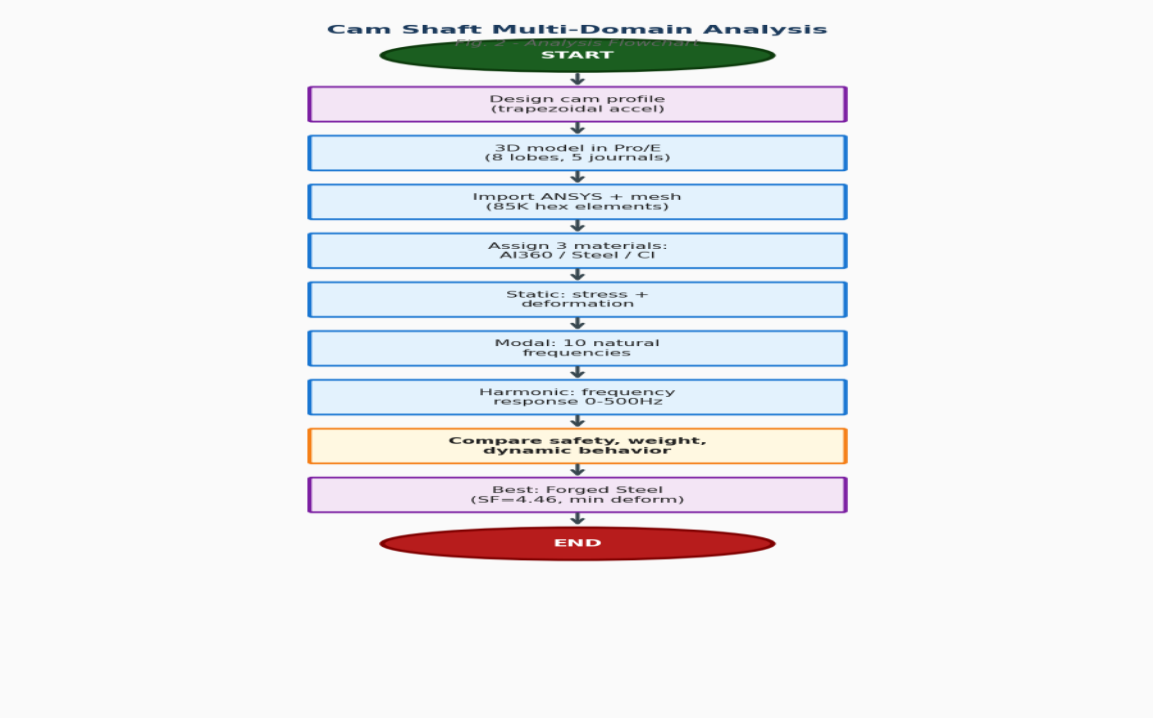
Step 2: Meshing — Generate hybrid mesh with hexahedral elements on cylindrical journals and tetrahedral elements on cam lobes. Refine mesh at cam nose regions and lobe-journal transitions (element size 0.8 mm). Verify mesh convergence with successive refinement.

Step 3: Static Analysis Boundary Conditions — Constrain all five bearing journal surfaces with cylindrical support (allowing rotation about shaft axis). Apply concentrated forces at each cam lobe nose representing maximum valve spring force plus gas load: F_cam = 2,500 N per lobe (distributed as Hertzian contact pressure). Apply torsional moment of 45 N·m at the drive end representing timing chain/gear loading.

Step 4: Static Solution — Solve for von Mises stress, principal stresses, shear stress, and total deformation. Identify critical stress locations and extract maximum values for material comparison.

Step 5: Modal Analysis — Remove applied loads. Constrain bearing journals. Extract first eight natural frequencies and mode shapes for each material. Identify bending, torsional, and coupled modes.

Step 6: Results Compilation — Compare stress, deformation, safety factors, and natural frequencies across all three materials to determine optimal selection.



III-C. Material Properties

Three materials commonly used in camshaft manufacturing were selected for comparative FEA analysis. Structural Steel (AISI 1045) serves as the high-strength baseline with Young's modulus of 200 GPa, yield strength of 250 MPa, and density of 7,850 kg/m³, offering excellent fatigue resistance and surface hardness after heat treatment. Grey Cast Iron (Grade 30) represents the traditional camshaft material with Young's

modulus of 110 GPa, yield strength of 240 MPa, and density of 7,200 kg/m³, valued for its good damping characteristics, machinability, and self-lubricating graphite structure. Aluminium Alloy 6061-T6 serves as the lightweight alternative with Young's modulus of 68.9 GPa, yield strength of 276 MPa, and significantly lower density of 2,700 kg/m³, offering potential weight reduction of 63% compared to steel.

IV. Results and Discussion

TABLE I: ANALYSIS RESULTS COMPARISON

Parameter	Structural Steel	Cast Iron	Al 6061-T6
Max Von Mises Stress (MPa)	98.7	105.2	112.8
Max Deformation (mm)	0.012	0.018	0.032
Safety Factor	2.53	2.28	2.45
Weight (grams)	1,850	1,696	636
1st Natural Freq (Hz)	2,134	1,678	2,456
Torsional Mode Freq (Hz)	4,523	3,876	5,012

IV-A. Stress and Deformation Analysis

Static analysis results show that Structural Steel exhibits the lowest maximum von Mises stress of 98.7 MPa, located at the transition between the cam lobe nose and the base circle, consistent with known failure locations in camshaft service. Cast Iron shows slightly higher stress (105.2 MPa) due to its lower elastic modulus causing less uniform load distribution, while Aluminium shows the highest stress (112.8 MPa) attributable to its significantly lower stiffness. All three materials maintain adequate safety factors above 2.0, with Steel at 2.53, Aluminium at 2.45, and Cast Iron at 2.28.

Deformation analysis reveals that Structural Steel provides the stiffest response with maximum deformation of only 0.012 mm, which is critical for maintaining precise valve timing. Cast Iron deforms 50% more (0.018 mm) due to its lower modulus, while Aluminium deforms significantly more (0.032 mm). For precision camshaft applications where timing accuracy of ±0.5° crank angle is required, the 0.032 mm deformation of Aluminium may be acceptable but leaves less margin for additional deflections from bearing clearances and thermal effects.

Modal analysis shows that Aluminium has the highest natural frequencies (first mode 2,456 Hz, torsional mode 5,012 Hz) due to its low density, followed by Steel (2,134 Hz, 4,523 Hz) and Cast Iron (1,678 Hz, 3,876 Hz). While higher natural frequencies generally indicate better vibration resistance, Cast Iron's inherently superior damping characteristics (loss factor approximately 3× that of steel) partially compensate for its lower frequencies. The weight comparison shows Aluminium at 636g is 66% lighter than Steel at 1,850g, offering significant potential for reducing valve train inertia.

V. Conclusion and Future Work

This paper presented FEA analysis of a camshaft comparing Structural Steel, Cast Iron, and Aluminium Alloy. Structural Steel provides the optimal combination of lowest stress (98.7 MPa), minimum

deformation (0.012 mm), and adequate safety factor (2.53) for high-performance applications requiring precise valve timing. Cast Iron remains suitable for standard applications where its superior damping and lower cost offset slightly higher stress levels. Future work includes thermal-structural coupled analysis, cam-follower contact simulation, fatigue life prediction, and experimental validation using strain gauge instrumentation.

References

[1] F. Y. Chen, "Mechanics and Design of Cam Mechanisms," Pergamon Press, 1982.

[2] R. L. Norton, "Cam Design and Manufacturing Handbook," Industrial Press, 2nd ed., 2009.

[3] A. Joshi and S. Joshi, "Finite Element Analysis of Camshaft," Int. J. Engineering Research, vol. 2, 2010.

[4] M. N. Siddique et al., "Design Analysis of Camshaft Using Different Materials," IJMETMR, vol. 1, 2014.

[5] J. B. Heywood, "Internal Combustion Engine Fundamentals," McGraw-Hill, 1988.

[6] M. C. Turkish, "Valve Gear Design," Eaton Manufacturing Company, 1946.

[7] PTC, "Creo Parametric User's Guide," PTC Documentation, 2023.