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Structural Dynamics And Natural Frequency Evaluation Of Camshafts Manufactured Using Gray Cast Iron, Inconel 718 And Aluminium Alloy

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Abstract: This project focuses on designing and analyzing a camshaft using SolidWorks and ANSYS. A 3D model was developed and tested under real conditions to study stress, deformation, and vibration. Three materials—Gray Cast Iron, Inconel 718, and Aluminium Alloy—were compared. Inconel 718 showed superior strength and fatigue resistance, Gray Cast Iron offered good damping and cost benefits, while Aluminium Alloy provided lightweight advantages. The study emphasizes material selection for improving

I. INTRODUCTION

I. The camshaft is one of the most important components in internal combustion (IC) engines, responsible for controlling the timing and operation of intake and exhaust valves. It converts the rotary motion of the crankshaft into reciprocating motion that opens and closes the valves at precise intervals. The accurate functioning of the camshaft ensures proper air-fuel intake and exhaust gas release, directly influencing engine efficiency, fuel consumption, and performance. Due to continuous rotation and contact with valve train elements, the camshaft is subjected to high cyclic loading, bending stresses, and wear. Therefore, its design and material selection must ensure reliability, strength, and long service life. In modern automotive industries, the demand for lightweight yet durable camshafts has grown significantly, prompting researchers and manufacturers to adopt advanced materials and design optimization techniques.

II. A well-designed camshaft not only enhances performance but also reduces maintenance requirements and increases overall durability of the engine. Traditional design methods often relied on empirical formulas and trial-and-error approaches, which were both time-consuming and less accurate. With the advancement of computer-aided design (CAD) and finite element analysis (FEA), engineers can now design and analyze mechanical components with higher precision before manufacturing. CAD software such as SOLIDWORKS allows accurate modelling of complex geometries like cam lobes, bearing journals, and fillets. Similarly, simulation tools such as ANSYS enable structural, modal, and fatigue analysis, providing insights into stress concentration zones, deformation levels, and vibration characteristics. This integration of design and analysis not only reduces production costs but also helps in achieving optimized camshaft performance.

III. The selection of suitable material plays a vital role in camshaft design, as the component experiences repeated contact stresses, torsional loads, and high wear. Historically, camshafts were manufactured using cast iron due to its low cost and good damping capacity. However, with the growing demand for higher performance and longer service life, advanced materials like alloy steels and case-hardened steels have been widely adopted. Alloy steel offers high strength and fatigue resistance, while case-hardened steel provides a tough core with a hard surface to resist wear. The choice of material directly affects the stress distribution, weight, and durability of the camshaft.

Hence, a comparative analysis of different materials under identical loading conditions helps in selecting the most efficient and reliable option for practical applications.

IV. Simulation-based design has become an essential practice in mechanical and automotive engineering. SOLIDWORKS, as a CAD tool, allows engineers to generate accurate 3D models with precise geometrical features, enabling better visualization of the camshaft structure. Once modelled, the geometry can be imported into ANSYS for finite element analysis. In ANSYS, static structural analysis provides stress and deformation values, modal analysis identifies natural frequencies to avoid resonance, and fatigue analysis estimates the service life under cyclic loads. These analyses offer valuable insights into component performance without the need for costly prototypes. By applying realistic boundary conditions such as valve-spring loads and rotational speeds, simulation results closely approximate real-world behaviour, ensuring that the camshaft design is both safe and efficient.

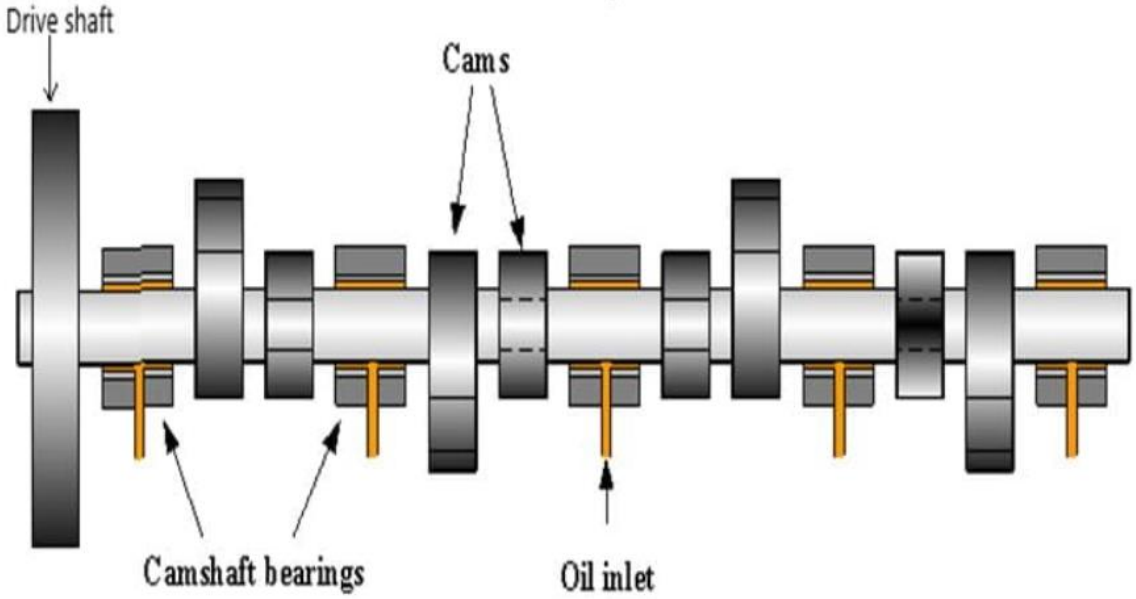

Fig: 1.1 Camshaft assembly

V. This project aims to design a camshaft using SOLIDWORKS and perform structural analysis and modal analysis in ANSYS to evaluate its performance under practical operating conditions. The study focuses on three materials—Gray Cast Iron, Inconel 718, and Aluminium Alloy—chosen for their relevance in automotive applications. The camshaft model is subjected to static, modal, and fatigue analyses to compare stress distribution, deformation, natural frequency, and fatigue life for each material. By analyzing the results, the project provides recommendations on the most suitable material for camshaft manufacturing, balancing performance, durability, and cost. The outcomes of this work contribute to the optimization of camshaft design and provide useful guidelines for industries seeking to improve engine reliability and efficiency.

VI. RESEARCH METHODOLOGY

The camshaft is one of the most crucial elements of an internal combustion engine, directly influencing engine efficiency, power output, fuel economy, and emissions. It regulates the opening and closing of intake and exhaust valves in synchronization with the piston’s movement. In modern high-performance engines such as the Nissan VQ35DD 3.5L V6 DOHC (bore 89 mm × stroke 93 mm), the camshaft is designed with precision to optimize combustion processes under varying operating conditions. The methodology for camshaft analysis involves studying its geometry, kinematics, dynamics, material properties, and stress characteristics to ensure durability and performance.

3.2 Camshaft analysis

Camshaft analysis can be broadly divided into the following stages:

1. Geometric and Kinematic Analysis

- Cam Profile Design: The lift curve is defined using polynomial, harmonic, or spline functions. The Nissan VQ35DD employs optimized lobe geometry for higher volumetric efficiency.
- Valve Lift and Duration: Key parameters include maximum lift (A), opening/closing angles, and valve overlap. These are critical for balancing performance and fuel economy.
- Timing Diagrams: Crank-angle versus valve-lift diagrams are plotted to visualize valve events.

2. Dynamic Analysis

- Spring Force Calculation: The valve spring seat force (~650 N) and open force (~1600 N at 10 mm lift) are evaluated to ensure valve control at high RPMs.
- Inertia Forces: Effective mass of the valve train (≈0.09 kg) is considered to calculate inertial loads at various speeds.
- Camshaft Speed: Since the camshaft rotates at half the crankshaft speed, analysis is carried out for operational ranges (e.g., 1000–7000 rpm crank speed).
- Vibration and Resonance: Dynamic analysis helps prevent valve float and ensures reliable operation at high speeds.

3. Force and Stress Analysis

- Contact Forces: Between cam lobe and follower are computed considering Hertzian contact theory.
- Bending and Torsional Stresses: Camshaft experiences torque due to valve spring resistance and is analyzed for fatigue life.
- Moment Analysis: Torque transmitted along the camshaft is determined at different operating speeds.

4. Material and Manufacturing Considerations

- Camshafts are commonly made of alloy steels or chilled cast iron with surface hardening treatments (case hardening, nitrating) to improve wear resistance.
- Material selection is based on tensile strength, fatigue resistance, machinability, and cost.

5. Computational Modeling and Simulation

- CAD Modeling: The camshaft geometry is modeled using software such as SOLID EDGE, SolidWorks, or NX.
- FEA Analysis: Finite Element Analysis is performed in ANSYS to predict stress distribution, deformation, and fatigue life.
- Dynamic Simulations: Valve motion and timing are verified through multi-body dynamics (e.g., using ADAMS or MATLAB/Simulink).

3.3 Application in Nissan VQ35DD Engine

The Nissan VQ35DD employs variable valve timing (VVT) and direct injection technologies. Camshaft analysis ensures:

- Smooth operation across a wide speed range.
- Optimization of fuel injection timing for efficiency.
- High torque at low RPMs and increased power at high RPMs.
- Reduced emissions through controlled valve overlap.

Camshaft analysis methodology combines theoretical calculations, experimental validation, and computational simulations to ensure reliability and performance. By studying cam profile geometry, valve dynamics, spring forces, and stress distribution, engineers can design camshafts that balance durability, efficiency, and power output. In modern engines like the Nissan VQ35DD, advanced analysis techniques enable precise control of valve timing, supporting both environmental regulations and performance demands.

3.4 Design Parameters

The main design parameters considered in this study are as follows:

- Valve spring seat force (F_s): 650 N
- Valve spring open force at maximum lift (F_s): 1600 N at 10 mm lift
- Effective mass of the valve system (m): 0.09 kg
- Valve lift amplitude (A): 0.01 m
- Effective radius of cam lobe (r): 0.018 m
- Camshaft rotational speed: Half of crankshaft speed
- Engine speed range considered: 800 to 6000 rpm (crankshaft)

3.5 Formulae Used

The following formulae were applied in the analysis:

1. Angular velocity of camshaft (rad/s):

$$\omega = \frac{2\pi N_{cam}}{60}$$

2. Inertia force on the valve (N):

$$F_i = m\omega^2 A$$

3. Total cam force(N):

$$F_{total} = F_s + F_i$$

4. Camshaft torque (Moment)(N-m):

$$M = (F_{total})r$$

5. Speed of the cam (RPM):

$$N_{cam} = \frac{N_{crank}}{2}$$

N_{crank}(RPM)	N_{cam}(RPM)	ω (rad/s)	F_i (N)	F_{total} (N)	Moment (N·m)
800	400	41.90	1.58	1601.58	28.83
1500	750	78.57	5.56	1605.56	28.90
3000	1500	157.14	22.22	1622.22	29.20
4500	2250	235.71	50.01	1650.01	29.70
6000	3000	314.29	88.90	1688.90	30.40

Table: 3.1 Calculation Tabular

MATERIAL SELECTION FOR CAMSHAFT

The selection of material for a camshaft is one of the most critical aspects of its design since the component experiences high cyclic loads, bending stresses, torsion, and continuous wear during engine operation. The chosen material must ensure long-term durability, reliability, and consistent engine performance. Key factors influencing the selection include mechanical strength, hardness, fatigue resistance, wear resistance, cost, and manufacturability. An ideal camshaft material should resist repeated stress cycles, maintain dimensional stability, and minimize surface wear or deformation over time.

Camshafts are commonly manufactured using a range of materials, but in this context, Gray Cast Iron, Inconel 718, and Aluminium Alloys are considered. Gray Cast Iron is a traditional material known for its good damping capacity, excellent wear resistance, and cost-effectiveness, making it suitable for standard applications. Inconel 718, a nickel-based superalloy, provides exceptional high-temperature strength, fatigue resistance, and corrosion resistance, which makes it ideal for extreme operating conditions or advanced engine designs. Aluminium Alloys, while lighter and easier to machine, offer reduced strength compared to

steels or superalloys, but their low density provides significant weight savings, improving engine efficiency and reducing inertia.
Mechanical properties such as tensile strength, yield strength, hardness, and fatigue resistance are compared to evaluate suitability. Gray Cast Iron provides excellent damping characteristics, which minimize vibrations and noise; however, its brittleness and relatively low tensile strength make it less suitable for high-performance or heavily loaded camshafts. Inconel 718 demonstrates outstanding tensile strength, creep resistance, and toughness even at elevated temperatures, enabling it to withstand severe stress cycles without degradation. Aluminium Alloys are not as strong as steel or nickel-based alloys, but their lightweight nature reduces rotational mass, enhancing dynamic performance and fuel efficiency in certain engine designs.
Finite Element Analysis (FEA) can be used to simulate stress distribution, deformation, and fatigue life for each material under realistic operating conditions. Parameters such as valve spring forces, rotational speeds, and torque loads are applied in the simulations. The results typically show that Inconel 718 outperforms the other two in terms of high-cycle fatigue resistance and minimal wear, though at a much higher cost. Gray Cast Iron, while cost-effective and adequate for standard duty cycles, is less reliable for high-load or high-speed applications. Aluminium Alloys provide advantages in weight-sensitive designs but may require reinforcement or surface treatments to improve wear resistance at the cam-follower interface.

4.1 Properties of Gray Cast Iron for Camshaft

Gray Cast Iron is traditionally used in camshaft manufacturing due to its good machinability, vibration damping, and cost-effectiveness. It typically exhibits a tensile strength in the range of 200–400 MPa and compressive strength above 600 MPa, which is sufficient for standard-duty engines. However, its relatively low yield strength and brittle nature limit its application in high-performance conditions. With a Brinell hardness of 180–220 HB, it provides good wear resistance at the cam-follower interface. Its damping capacity is excellent, reducing noise and vibration during engine operation, which improves overall durability of the valve train system.

The physical properties of Gray Cast Iron include a density of about 7.0–7.3 g/cm³ and thermal conductivity of 50–60 W/m·K, enabling effective heat dissipation. Its coefficient of thermal expansion is approximately 11×10^{-6} /°C, ensuring dimensional stability during thermal cycles. While corrosion resistance is moderate, protective coatings or lubrication reduce degradation. The material is also highly machinable, making it cost-effective for mass production. Although its fatigue resistance is lower than steels, it remains suitable for standard passenger vehicles and industrial engines where extreme loads are not encountered.

4.2 Properties of Inconel 718 for Camshaft

Inconel 718, a nickel-based superalloy, is known for its exceptional strength and fatigue resistance, especially under high-temperature conditions. It exhibits tensile strength in the range of 1,000–1,400 MPa and yield strength of 700–1,200 MPa, making it far superior to cast iron and aluminium alloys for extreme-duty camshafts. Its hardness can reach 330–400 HB, ensuring outstanding wear resistance at the cam-follower interface. Inconel 718 maintains mechanical strength up to temperatures of 700°C, making it ideal for engines exposed to high thermal loads.

The physical properties include a density of about 8.19 g/cm³, thermal conductivity of only 11–15 W/m·K, and a coefficient of thermal expansion of 13×10^{-6} /°C. Though heavier and less conductive than steel or aluminium, it maintains dimensional stability and resists creep deformation under prolonged stress. Inconel 718 also exhibits excellent corrosion and oxidation resistance, ensuring long service life in harsh environments. Machinability is lower compared to cast iron or aluminium, but advanced CNC techniques and appropriate tooling allow precision shaping. Due to its high cost, Inconel 718 is generally reserved for aerospace-grade or high-performance racing engines where reliability under extreme conditions is paramount.

4.3 Properties of Aluminium Alloy for Camshaft

Aluminium Alloys are sometimes used for specialized camshaft applications where weight reduction is a priority. With a tensile strength typically ranging between 200–400 MPa and yield strength of 150–300 MPa, they are weaker than steels or super alloys but provide sufficient strength for lightweight or low-load camshafts. The Brinell hardness ranges from 60–120 HB, which is relatively low, meaning wear resistance must often be enhanced through coatings or surface treatments. The main advantage of aluminium alloys lies in their low density (~2.7 g/cm³), which significantly reduces the camshaft's rotational inertia, improving engine response and efficiency.

Aluminium Alloys also exhibit high thermal conductivity (150–200 W/m·K) and a higher coefficient of thermal expansion (22–24 × 10^{-6} /°C) compared to steels. This means they dissipate heat quickly but may experience more dimensional changes with temperature fluctuations, requiring careful design considerations. Their corrosion resistance is good, particularly with protective anodizing or alloying. Machinability is excellent, allowing precise shaping of lobes and journals at lower cost. However, the relatively low fatigue resistance and surface durability limit aluminium camshafts to specialized or experimental lightweight engine designs rather than mainstream high-performance or heavy-duty engines.

4.4 Comparison of Camshaft Materials

In camshaft design, selecting the right material directly impacts performance, reliability, and service life. **Gray Cast Iron** is widely used in standard applications due to its good vibration damping, adequate wear resistance, and cost-effectiveness; however, its lower tensile strength and fatigue resistance limit its use in high-performance engines. **Inconel 718**, a nickel-based super alloy, offers exceptional tensile and yield strength, outstanding fatigue life, and excellent wear resistance, even at elevated temperatures, making it ideal for extreme-duty or high-performance engines. **Aluminium Alloys**, though not as strong as cast iron or super alloys, provide significant weight savings, high thermal conductivity, and good machinability, making them suitable for specialized lightweight engine applications where reducing inertia and improving efficiency are critical. By comparing properties such as mechanical strength, fatigue resistance, wear resistance, weight, and cost, engineers can choose a material that best balances performance, durability, and manufacturability for the intended application.

4.5 Comparison of Gray Cast Iron and Inconel 718

Gray Cast Iron and Inconel 718 serve very different roles in camshaft manufacturing. **Gray Cast Iron** provides adequate strength, excellent vibration damping, and good wear resistance at a low cost, making it practical for mass-produced engines operating under moderate stresses. However, its brittleness and relatively low fatigue resistance limit its use in high-performance conditions. **Inconel 718**, in contrast, offers superior tensile and yield strength, remarkable fatigue life, and the ability to retain mechanical integrity at high temperatures, making it suitable for advanced or extreme engine environments. While Gray Cast Iron excels in damping capacity and economic feasibility, Inconel 718 is preferred for applications where long-term durability, high thermal stability, and extreme load handling are required. The choice between the two depends on whether the priority is cost-effectiveness and damping (Gray Cast Iron) or maximum performance and reliability (Inconel 718).

4.6 Summary of Material Properties

In camshaft design, material selection must balance strength, wear resistance, fatigue behaviour, weight, and cost. **Gray Cast Iron** offers good damping capacity, adequate wear resistance, and low cost, making it well-suited for standard-duty engines, though its brittleness restricts use in high-load scenarios. **Inconel 718** delivers unmatched mechanical strength, fatigue resistance, and thermal stability, making it the best choice for high-performance or extreme applications, albeit at a high manufacturing cost. **Aluminium Alloys**, while weaker and less wear-resistant, provide substantial weight savings and excellent thermal conductivity, which can enhance engine efficiency in lightweight or specialized designs. The selection ultimately depends on the engine's performance requirements, expected loading conditions, cost constraints, and whether the priority lies in durability, high-temperature strength, or weight reduction.

Property	Gray Cast Iron	Inconel 718	Aluminium Alloy
Tensile Strength	Moderate (200–400 MPa)	Very high (1,000–1,400 MPa)	Low to moderate (200–400 MPa)
Yield Strength	Low (150–300 MPa)	Very high (700–1,200 MPa)	Low (150–300 MPa)
Hardness	Moderate (180–220 HB)	High (330–400 HB)	Low (60–120 HB)
Fatigue Resistance	Low to moderate	Excellent	Low to moderate
Wear Resistance	Moderate	Excellent	Low (requires coatings)
Damping Capacity	High (good vibration damping)	Low (poor damping)	Low (poor damping)
Machinability	Excellent	Difficult (requires advanced tooling)	Excellent
Corrosion Resistance	Moderate	Excellent (oxidation & corrosion resistant)	Good (improves with anodizing)
Density	7.0–7.3 g/cm³	8.19 g/cm³	2.7 g/cm³
Thermal Conductivity	50–60 W/m·K	Low (11–15 W/m·K)	High (150–200 W/m·K)
Coefficient of Expansion	~11 × 10⁻⁶ /°C	~13 × 10⁻⁶ /°C	~23 × 10⁻⁶ /°C
Cost	Low	Very high	Moderate
Application Suitability	Standard, cost-effective engines	Extreme-duty/high-performance engines	Lightweight/specialized applications

Table: 4.1 Material comprehensive comparison

4.7 Comparative Discussion of Camshaft Materials

In terms of mechanical strength, **Inconel 718** exhibits the highest tensile and yield strength, making it capable of withstanding extreme bending, torsional, and cyclic loads even at elevated temperatures. **Gray Cast Iron** provides only moderate tensile strength and lower fatigue resistance, which limits its use in high-performance or heavy-duty engines but remains adequate for standard applications. **Aluminium Alloys**, while lightweight, possess lower strength and fatigue life compared to both Inconel 718 and cast iron, restricting their use to specialized lightweight engine designs where weight reduction is prioritized over absolute strength.

Wear resistance is a critical factor in camshaft design, especially at the cam lobe–follower interface. **Inconel 718** excels due to its high surface hardness and excellent resistance to both wear and thermal degradation, ensuring long service life under severe operating conditions. **Gray Cast Iron** provides moderate wear resistance, sufficient for conventional duty cycles, while **Aluminium Alloys** have poor wear resistance unless enhanced with coatings or surface treatments. This comparison highlights how wear behaviour strongly influences the suitability of each material for specific applications.

Another important factor is vibration damping. **Gray Cast Iron** demonstrates superior damping capacity, reducing engine vibration and noise, which contributes to smoother operation. In contrast, **Inconel 718** and **Aluminium Alloys** have relatively low damping capacity, meaning engines using these materials may require additional design considerations to manage vibrations. In terms of machinability, **Aluminium Alloys** are the easiest to machine with high precision at lower cost, followed by **Gray Cast Iron**, which is also highly machinable. **Inconel 718**, due to its toughness and work-hardening characteristics, is the most difficult to machine, requiring advanced tools and processes.

Cost and application suitability play a decisive role in material selection. **Gray Cast Iron** is the most economical choice, making it suitable for standard or mass-market engines where cost-effectiveness is critical. **Inconel 718**, while offering unmatched mechanical and thermal performance, is significantly more expensive, restricting its use to high-performance, aerospace-grade, or racing engines where durability under extreme conditions justifies the cost. **Aluminium Alloys** occupy a middle ground in terms of cost and are preferred in specialized cases where weight reduction and thermal conductivity provide distinct advantages, despite their lower strength.

Material	Tensile	Yield	Fatigue	Wear	Damping	Machinability	Cost
Gray Cast Iron	5	4	4	6	9	9	10
Inconel 718	10	10	10	9	3	4	2
Aluminium Alloy	6	6	6	5	6	10	7

Table: 4.2 Data Values (0–10 scale)

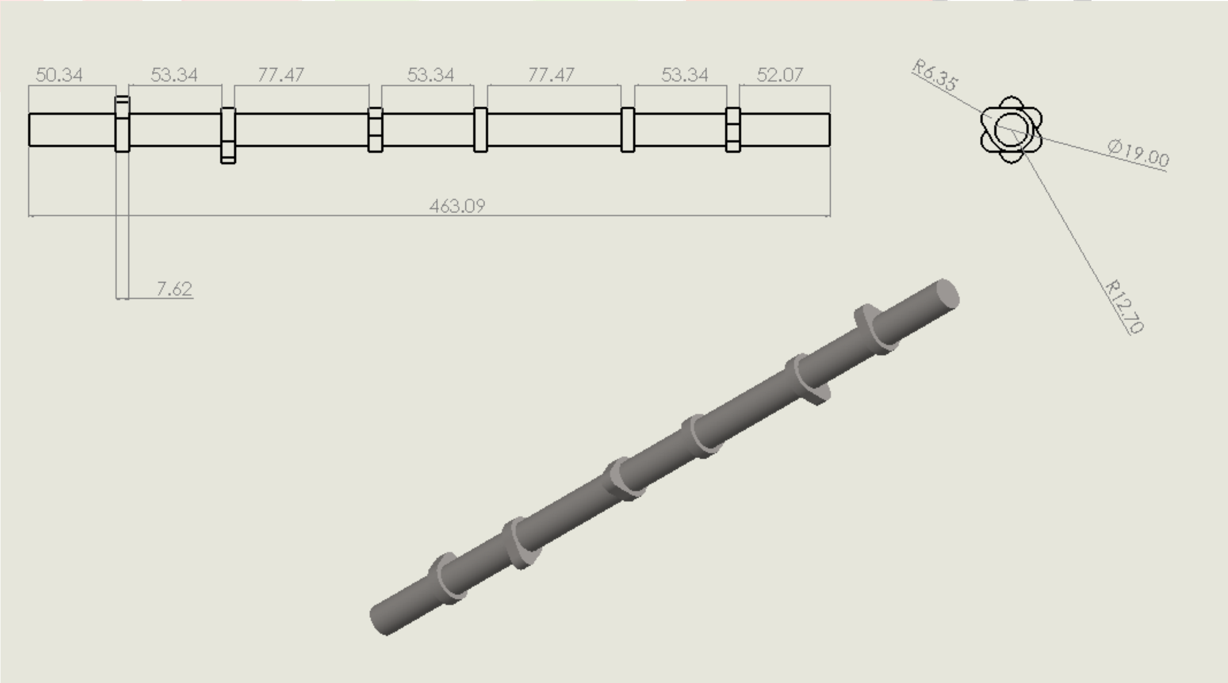

Fig: 5.1 Camshaft sketch

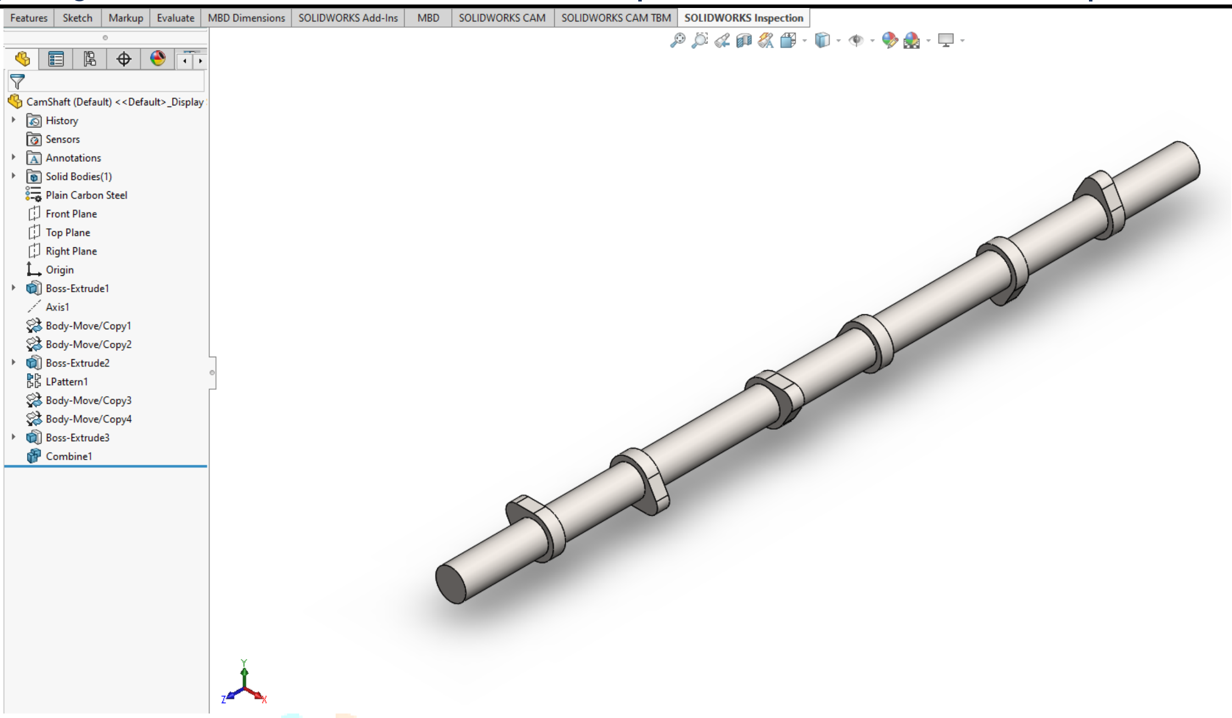

Fig: 5.2 Camshaft detail view

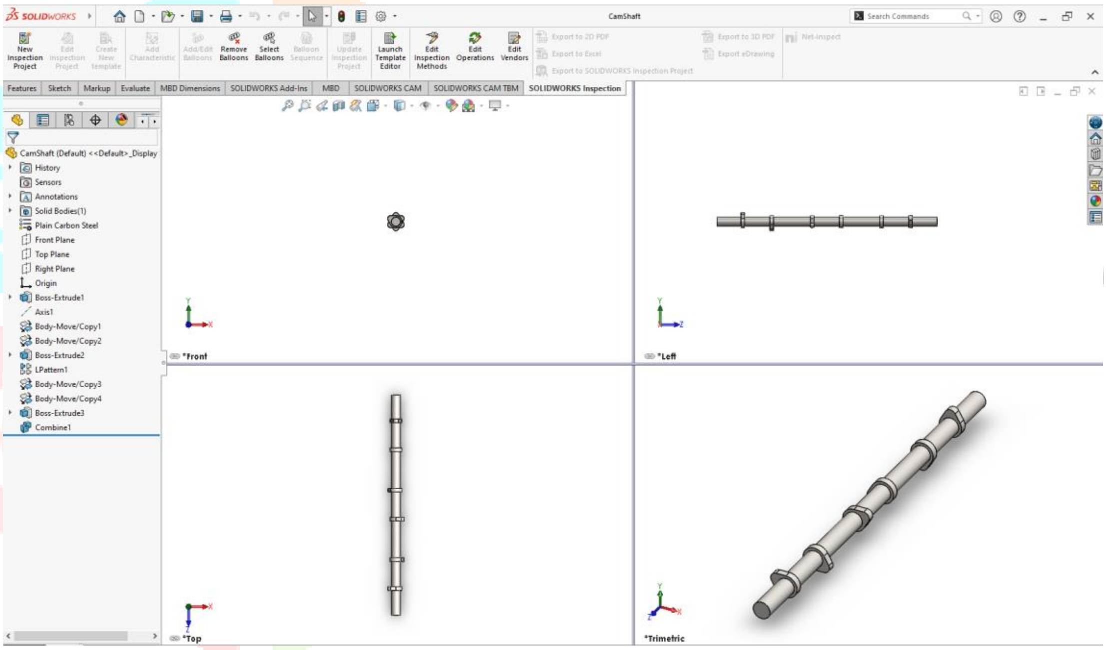

Fig: 5.3 Camshaft model

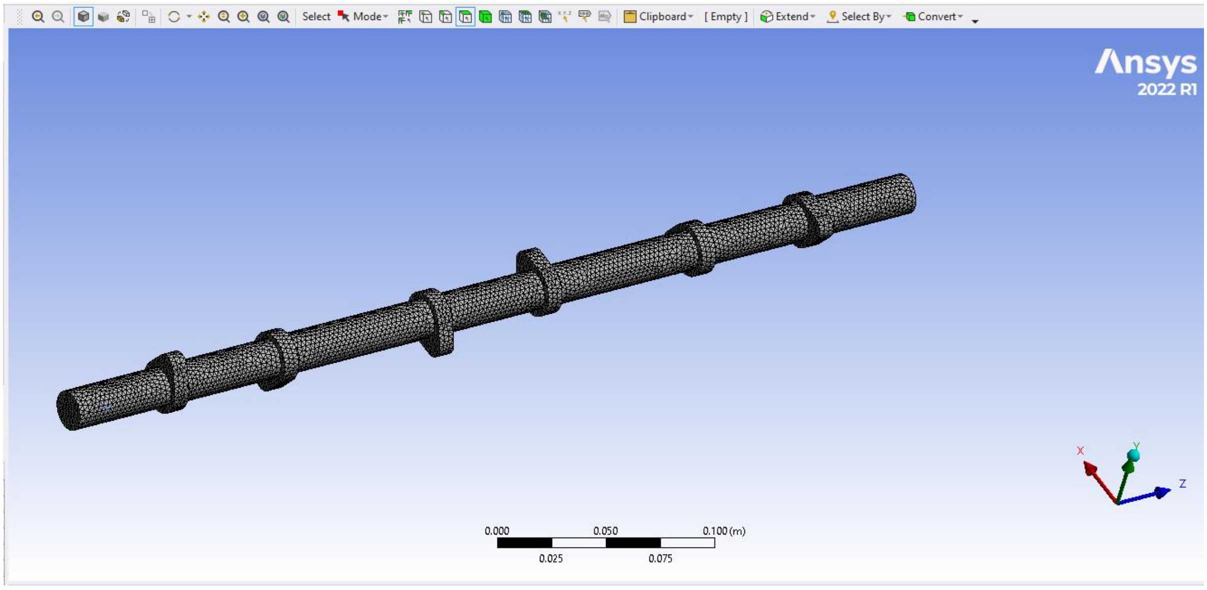

Fig: 6.1Mesh of camshaft

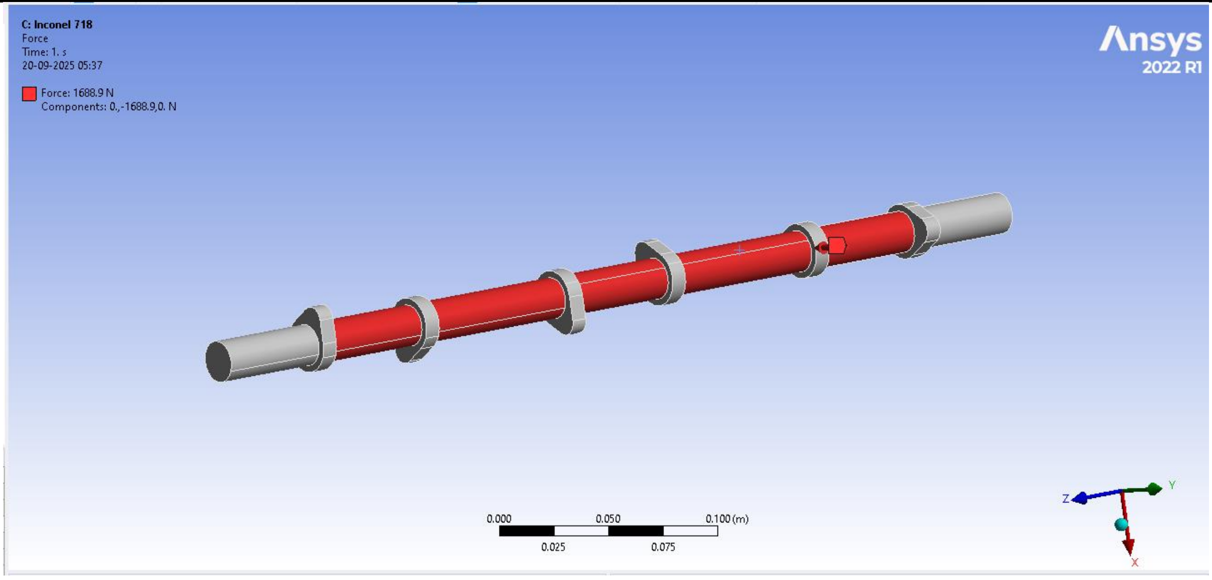

Fig: 6.4 Force of camshaft

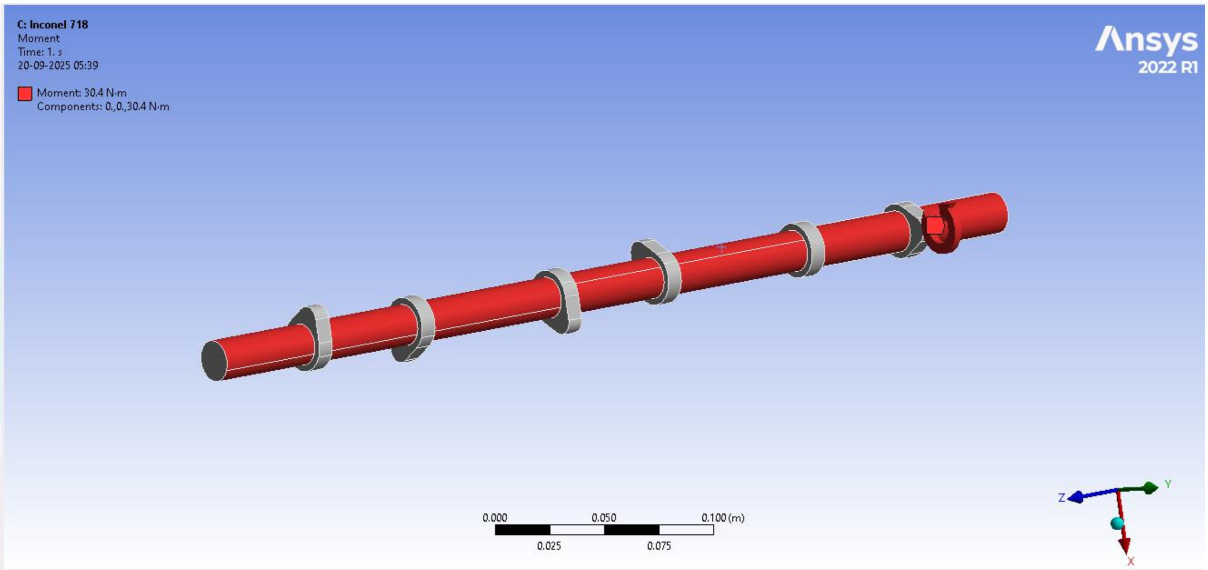

Fig: 6.5 Momentum of camshaft

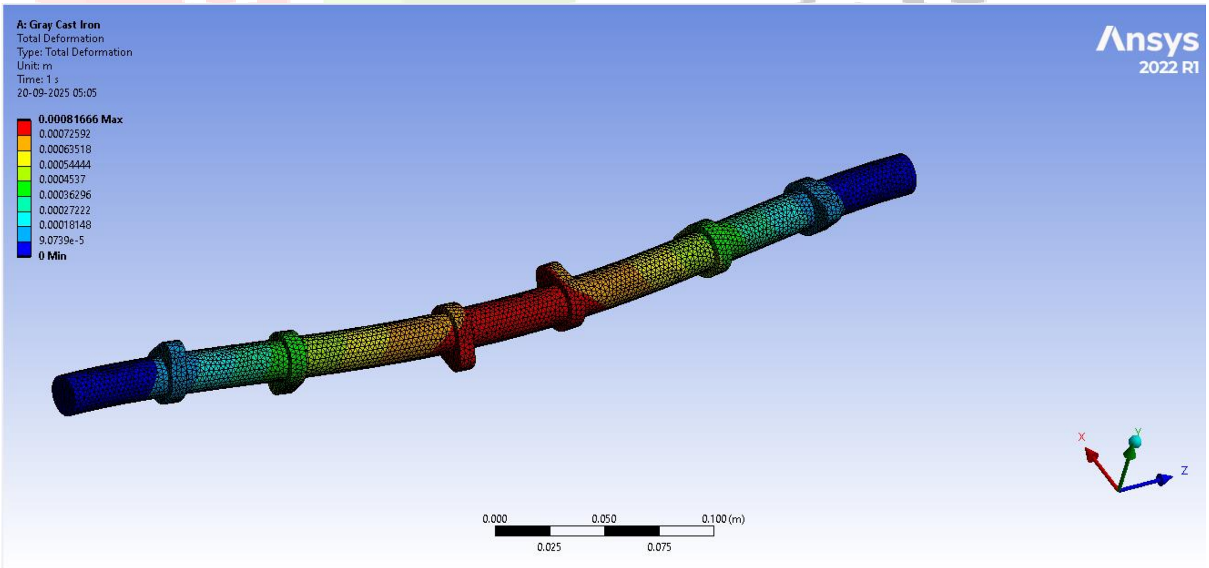

Fig: 6.6 Total Deformation of cam shaftof Gray Cast Iron

RESULTS

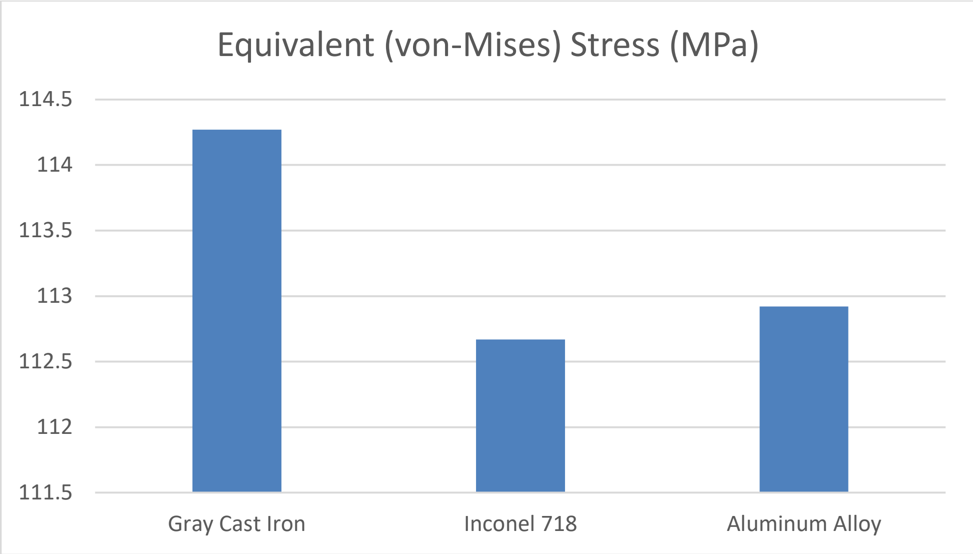

Fig:7.1 Equivalent (Von-Mises) Stress (MPa)

The bar chart illustrates the maximum equivalent (von-Mises) stress values obtained from a structural analysis in ANSYS for three different materials: Gray Cast Iron, Inconel 718, and Aluminium Alloy. Von-Mises stress is a critical parameter used in structural analysis to determine whether a material will yield or fail under a given loading condition. Among the three materials tested, Gray Cast Iron exhibits the highest von-Mises stress value of 114.27 MPa, followed by Aluminium Alloy at 112.92 MPa, and Inconel 718 at 112.67 MPa. This indicates that under identical loading conditions, Gray Cast Iron experiences slightly higher stress levels compared to the other two materials.
From a design perspective, the material selection is not solely based on the von-Mises stress value but also on how close this stress is to the material's yield strength. Although Gray Cast Iron shows the highest stress, it may still be suitable if its yield strength is significantly higher than the induced stress. However, Inconel 718, despite showing the lowest von-Mises stress, is well known for its superior strength, fatigue resistance, and thermal stability, making it the best candidate among the three for high-performance and long-life applications. Aluminium Alloy, while lightweight and showing moderate stress, is more suited for applications prioritizing weight reduction over extreme strength. Therefore, Inconel 718 is considered the best choice due to its combination of low induced stress and excellent material properties.

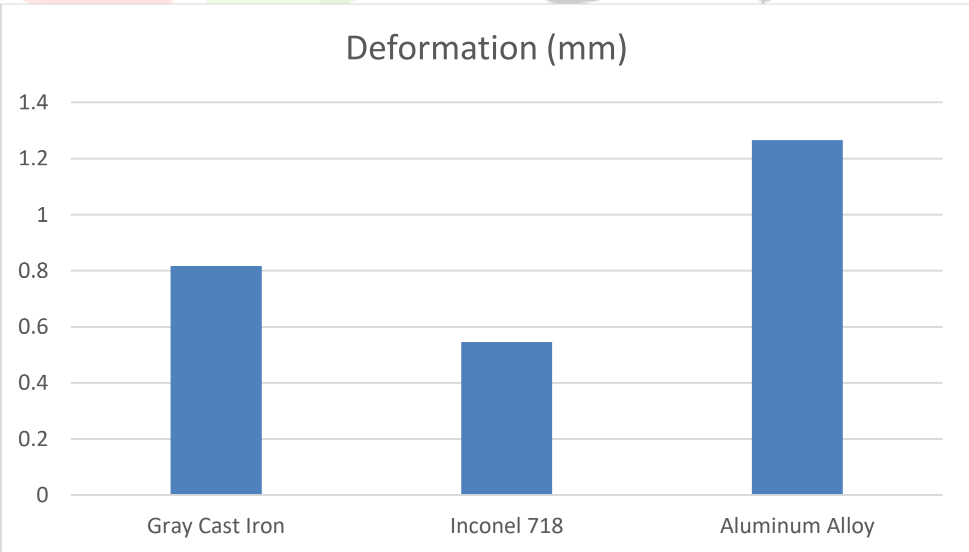

Fig: 7.2 Deformation (mm)

The bar chart represents the maximum total deformation values obtained from structural analysis in ANSYS for three materials: Gray Cast Iron, Inconel 718, and Aluminium Alloy. Deformation indicates the displacement of the material under applied loading conditions, which is a key parameter in evaluating stiffness and structural stability. Among the tested materials, Inconel 718 exhibits the lowest deformation of

0.5448 mm, followed by Gray Cast Iron with 0.8167 mm, while Aluminium Alloy shows the highest deformation at 1.2653 mm. This result highlights the significant differences in stiffness between the materials, where Inconel 718 provides the highest resistance to deformation and Aluminium Alloy the least. In terms of material selection, lower deformation is generally desirable as it ensures better dimensional stability and reliability under service conditions. Although Gray Cast Iron performs moderately well, its brittleness and lower toughness make it less suitable for applications where durability and resistance to mechanical fatigue are critical. Aluminium Alloy, despite being lightweight, exhibits the largest deformation, which could compromise precision and strength in structural applications. On the other hand, Inconel 718 proves to be the best choice among the three, offering minimal deformation combined with its well-known properties of high strength, corrosion resistance, and superior fatigue performance, making it ideal for demanding engineering applications.

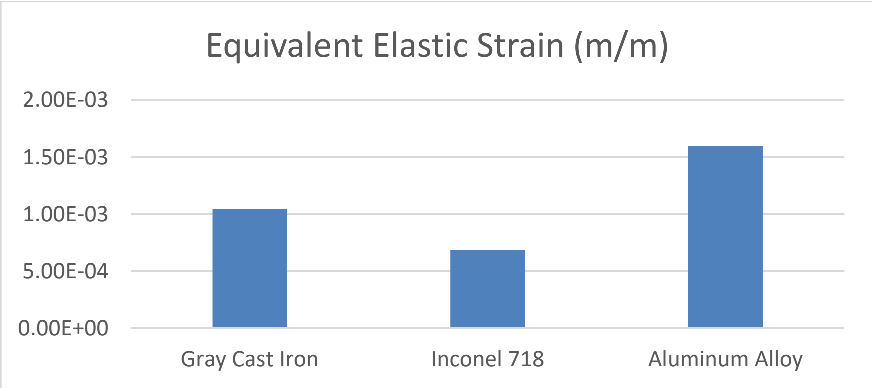

Fig: 7.3 Equivalent Elastic Strain (m/m)

The analysis shows Aluminium Alloy has the highest elastic strain (1.60×10^{-3} m/m), Gray Cast Iron moderate (1.04×10^{-3} m/m), and Inconel 718 the lowest (6.86×10^{-4} m/m). Lower strain indicates higher stiffness; hence, Inconel 718, with superior strength, fatigue resistance, and stability, is the most suitable and durable material for camshaft applications.

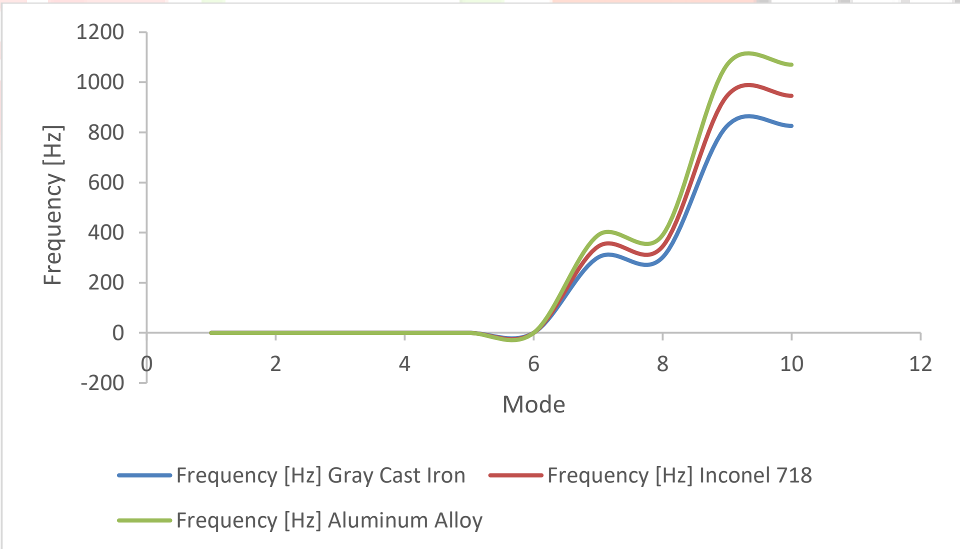

Fig: 7.4 Frequency (Hz)

The above graph presents the modal analysis results of a camshaft for three different materials: Gray Cast Iron, Inconel 718, and Aluminium Alloy, showing their corresponding natural frequencies at different modes. The first two modes for all materials record zero frequency, representing rigid body motions with no deformation. From the third to sixth modes, the frequencies are extremely low, in the range of 10−410^{-4}10−4 to 10−310^{-3}10−3 Hz, which correspond to negligible elastic vibrations and local deformations of the shaft structure. These values indicate that the camshaft maintains structural stability in its early modes, with minimal susceptibility to resonance at lower vibration levels.

A significant increase in natural frequency is observed from the seventh mode onward, where the values rise sharply into the hundreds of hertz. For example, at mode 7, Gray Cast Iron records 300.6 Hz, Inconel 718 records 344.69 Hz, and Aluminium Alloy achieves the highest at 389.76 Hz. This trend continues in higher modes, with Aluminium Alloy consistently showing the highest natural frequencies, followed by Inconel 718 and Gray Cast Iron. These results suggest that lighter and stiffer materials such as Aluminium Alloy offer superior resistance to resonance within typical engine operating ranges, while denser materials like Cast Iron have comparatively lower frequencies. Such comparisons are vital in material selection to ensure that the camshaft's natural frequencies do not coincide with engine excitation frequencies, thereby preventing resonance and enhancing durability.

Conclusion

The present structural analysis was carried out using ANSYS to evaluate and compare the performance of three materials: Gray Cast Iron, Inconel 718, and **Aluminium** *Alloy, under identical loading and boundary conditions. The study considered three critical performance indicators: maximum equivalent (von-Mises) stress, maximum total deformation, and maximum equivalent elastic strain. These parameters collectively provide a comprehensive understanding of how the materials behave under load, thereby guiding engineers in making informed decisions regarding material selection for structural and mechanical components.*

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