DESIGN, MODELING, AND MANUFACTURING OF A SIX-CYLINDER ENGINE CAMSHAFT

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ABSTRACT

The camshaft is one of the most critical components of an internal combustion engine, as it controls the opening and closing of intake and exhaust valves, directly influencing engine performance, fuel efficiency, and emission characteristics. This project focuses on the modelling and manufacturing of a six-cylinder engine camshaft by integrating modern Computer-Aided Design (CAD) techniques with precision manufacturing processes. Initially, a three-dimensional (3D) model of the camshaft is developed using CAD software based on standard engine specifications, considering parameters such as cam profile, shaft dimensions, lobe spacing, journal diameter, and timing sequence. The digital model is evaluated to ensure dimensional accuracy and proper alignment of all cam lobes required for a six-cylinder engine configuration. Following the modelling phase, suitable engineering materials are selected based on mechanical strength, wear resistance, hardness, and fatigue performance. The manufacturing process includes machining operations such as turning, milling, grinding, and precision finishing to produce the required camshaft geometry. Heat treatment and surface finishing techniques are also incorporated to improve hardness, durability, and service life under high-speed operating conditions. Dimensional inspection and quality verification are performed to ensure compliance with design specifications and manufacturing standards. The developed camshaft is expected to provide accurate valve timing, reduced friction, improved mechanical reliability, and enhanced engine efficiency. The proposed methodology demonstrates the importance of integrating CAD modelling with advanced manufacturing technologies to produce high-quality engine components while reducing production time and manufacturing cost. This study contributes to the development of reliable and precision-engineered camshafts suitable for modern six-cylinder automotive and industrial engine applications.

Keywords: Camshaft, Six-Cylinder Engine, Computer-Aided Design (CAD), Manufacturing, Valve Timing, Precision Machining, Heat Treatment, Surface Finishing, Mechanical Design, Internal Combustion Engine.

I. INTRODUCTION

The camshaft is one of the most important mechanical components in an internal combustion engine because it controls the precise opening and closing of the intake and exhaust valves. Accurate valve timing directly influences engine performance, fuel consumption, combustion efficiency, and exhaust emissions. In a six-cylinder engine, the camshaft must operate with high dimensional accuracy to ensure synchronized valve movement across all cylinders. Any deviation in cam profile or lobe positioning can lead to poor engine performance, increased fuel consumption, higher emissions, and premature component wear. Traditionally, camshafts were manufactured using conventional machining methods that required extensive manual inspection and multiple production stages. However, advancements in Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), and precision machining technologies have significantly improved the design and manufacturing process. Three-dimensional modelling enables engineers to visualize the complete geometry, verify dimensional accuracy, and optimize the design before production begins. The integration of digital modelling with modern manufacturing processes has reduced production time, minimized material waste, and enhanced product quality. As automotive industries continue to demand lightweight, durable, and highly efficient engine components, the development of precision-engineered camshafts has become increasingly important for modern engine systems **[1–8]**.

The manufacturing of a six-cylinder engine camshaft involves several precision engineering processes, including material selection, turning, milling, grinding, heat treatment, and final dimensional inspection. Each manufacturing stage contributes to achieving the required mechanical strength, wear resistance, fatigue life, and surface finish necessary for continuous engine operation. Alloy steels and hardened cast irons are commonly selected because of their superior mechanical properties and resistance to cyclic loading. Modern CNC machining centers have transformed camshaft production by providing exceptional dimensional accuracy and repeatability while reducing manufacturing errors. Heat treatment processes such as induction hardening and carburizing further improve surface hardness and increase resistance to wear during long-term engine operation. In addition, precision grinding is employed to obtain accurate cam profiles and smooth surface finishes that minimize friction between the camshaft and valve train components. The combination of advanced manufacturing technologies and quality inspection techniques ensures reliable engine performance, improved durability, and reduced maintenance requirements. These developments have made precision manufacturing an essential aspect of modern automotive engineering and engine component production **[9–17]**.

Recent developments in automotive engineering emphasize the use of digital design tools and intelligent manufacturing techniques to produce high-performance engine components with greater accuracy and efficiency. Computer-Aided Design (CAD) software enables engineers to create detailed three-dimensional models of camshafts while allowing dimensional verification, assembly validation, and design optimization before fabrication. Manufacturing simulations further reduce production risks by identifying machining challenges and improving process planning. This project focuses on the modelling and manufacturing of a six-cylinder engine camshaft using modern CAD software and precision machining techniques. The developed model incorporates accurate cam profiles, journal dimensions, lobe spacing, and shaft geometry based on standard engine design requirements. Following the modelling phase, the manufacturing process is planned using suitable machining operations and quality inspection methods to ensure dimensional accuracy and mechanical reliability. The proposed methodology aims to produce a durable camshaft with improved valve timing accuracy, enhanced wear resistance, and extended service life. The study demonstrates that integrating CAD modelling with modern manufacturing technologies provides an efficient and economical approach for producing high-quality engine components capable of meeting the performance requirements of contemporary automotive applications **[18–25]**.

II. SURVEY OF RESEARCH

1. CAD-Based Design of Automotive Camshafts

Recent studies have emphasized the importance of Computer-Aided Design (CAD) in the development of automotive camshafts. Researchers have reported that three-dimensional modelling improves dimensional accuracy and enables engineers to visualize complex cam profiles before manufacturing. CAD software allows modifications to cam lobe geometry, journal dimensions, and shaft alignment without increasing production costs. Digital modelling also facilitates interference checking, assembly validation, and design optimization during the initial stages of product development. The implementation of CAD has significantly reduced design errors, shortened development cycles, and improved communication between design and manufacturing teams. Furthermore, virtual modelling minimizes the requirement for multiple physical prototypes, thereby reducing material consumption and manufacturing expenses. These investigations conclude that CAD technology has become an essential tool for producing precision-engineered camshafts with improved reliability and manufacturing efficiency **[1]**.

2. Precision Manufacturing Techniques for Camshaft Production

Modern research has focused on improving camshaft manufacturing through advanced machining technologies. CNC turning, milling, grinding, and precision finishing have significantly increased dimensional accuracy while reducing production time. Researchers have investigated different machining parameters such as cutting speed, feed rate, and tool geometry to achieve superior surface quality and improved productivity. Heat treatment methods including induction hardening and carburizing have also been evaluated to increase surface hardness and wear resistance. Experimental investigations indicate that combining precision machining with appropriate heat treatment considerably enhances fatigue strength and service life. These manufacturing improvements contribute to better valve timing accuracy and lower maintenance requirements in automotive engines. The studies demonstrate that modern machining technologies play a significant role in producing durable and high-performance camshafts **[2]**.

3. Material Selection for High-Performance Camshafts

Several investigations have examined suitable engineering materials for automotive camshaft manufacturing. Alloy steels, forged steel, and chilled cast iron are widely used because of their excellent strength, hardness, and fatigue resistance. Researchers have compared the mechanical performance of different materials under cyclic loading and high-temperature operating conditions. The findings indicate that alloy steel provides superior wear resistance and longer operational life compared with conventional materials. Surface treatment techniques such as nitriding and induction hardening further improve durability by increasing surface hardness while maintaining core toughness. Proper material selection not only enhances mechanical performance but also reduces frictional wear between the camshaft and valve train components. These studies confirm that selecting appropriate materials is critical for achieving reliable engine operation and extending component lifespan **[3]**.

4. Manufacturing Quality Control and Dimensional Inspection

Quality control has become an essential aspect of camshaft manufacturing because even minor dimensional errors can affect engine performance. Researchers have investigated coordinate measuring machines (CMM), laser scanners, and digital inspection systems to verify cam profiles, journal diameters, and shaft alignment. Advanced inspection techniques provide accurate dimensional measurements while reducing inspection time compared with conventional methods. Statistical quality control has also been implemented to monitor manufacturing consistency and minimize production defects. The studies reveal that integrating precision inspection with automated manufacturing significantly improves product quality and reduces rejection rates. Accurate dimensional verification ensures proper valve timing, smooth engine operation, and improved reliability. Consequently, modern quality control systems have become indispensable in automotive component manufacturing **[4]**.

5. Optimization of Camshaft Geometry for Engine Performance

Recent research has concentrated on optimizing camshaft geometry to improve engine efficiency and overall performance. Various numerical and experimental approaches have been employed to optimize cam lobe profiles, lift characteristics, valve timing, and lobe spacing. Researchers observed that optimized cam geometry improves air-fuel intake, combustion efficiency, and exhaust gas removal while reducing mechanical losses. Simulation-based optimization has enabled engineers to evaluate multiple design alternatives before manufacturing, resulting in lower production costs and improved engine performance. These investigations highlight that optimized camshaft design contributes to enhanced fuel economy, reduced emissions, and smoother engine operation. The integration of numerical modelling with manufacturing processes has therefore become an important strategy for developing advanced automotive engine components **[5]**.

6. Integrated CAD and Manufacturing Systems for Camshaft Development

Recent advancements in Industry 4.0 have encouraged the integration of CAD, CAM, CNC machining, and digital quality inspection for manufacturing automotive camshafts. Researchers have demonstrated that digital manufacturing systems improve production planning, reduce machining errors, and enhance process automation. Computer-integrated manufacturing enables seamless data transfer from CAD models to CNC machines, ensuring accurate production of complex cam profiles. Automated inspection systems further improve manufacturing precision by verifying critical dimensions immediately after machining. The integration of digital technologies has resulted in shorter production cycles, improved product consistency, and lower manufacturing costs. These studies conclude that combining advanced CAD modelling with intelligent manufacturing techniques significantly enhances the efficiency, quality, and reliability of six-cylinder engine camshaft production while supporting modern automotive manufacturing requirements **[6]**.

III. PROPOSED SYSTEM

The proposed system focuses on the modelling and manufacturing of a six-cylinder engine camshaft using modern Computer-Aided Design (CAD) software and precision manufacturing techniques. The primary objective is to develop a highly accurate camshaft that ensures precise valve timing, improved engine performance, enhanced durability, and reliable operation. The system begins with the collection of engine design specifications, including the number of cylinders, firing order, cam lobe profile, shaft diameter, journal dimensions, valve lift, cam angle, and lobe spacing. These design parameters are used to create a three-dimensional (3D) camshaft model using CAD software such as SolidWorks, CATIA, or Autodesk Inventor. The digital model enables engineers to verify dimensional accuracy, identify design errors, and perform assembly validation before manufacturing. After the completion of the CAD model, the design is analyzed to ensure proper alignment of cam lobes, shaft journals, and bearing surfaces. The generated model is then converted into manufacturing data compatible with Computer-Aided Manufacturing (CAM) software for machining process planning. Suitable engineering materials such as alloy steel or hardened cast iron are selected based on mechanical strength, hardness, wear resistance, and fatigue life. The manufacturing process includes CNC turning for shaft preparation, milling for rough cam profile generation, precision grinding for final cam lobe geometry, and drilling operations where required. Heat treatment methods such as induction hardening are applied to improve surface hardness and wear resistance. Surface finishing processes are subsequently performed to obtain the required dimensional accuracy and low surface roughness. Finally, the manufactured camshaft undergoes dimensional inspection and quality verification using precision measuring instruments such as Vernier calipers, micrometers, dial gauges, and Coordinate Measuring Machines (CMM). Critical parameters including cam profile accuracy, lobe spacing, journal diameter, shaft straightness, and surface finish are inspected to ensure compliance with design specifications. If deviations are identified, corrective machining is performed before final approval. The proposed system integrates digital modelling, advanced manufacturing technologies, heat treatment, and quality inspection into a unified production workflow. This systematic approach minimizes manufacturing errors, reduces production time, lowers material waste, and improves product consistency. The developed six-cylinder engine camshaft is expected to provide accurate valve operation, improved fuel efficiency, reduced mechanical wear, and enhanced engine reliability, making it suitable for modern automotive and industrial engine applications.

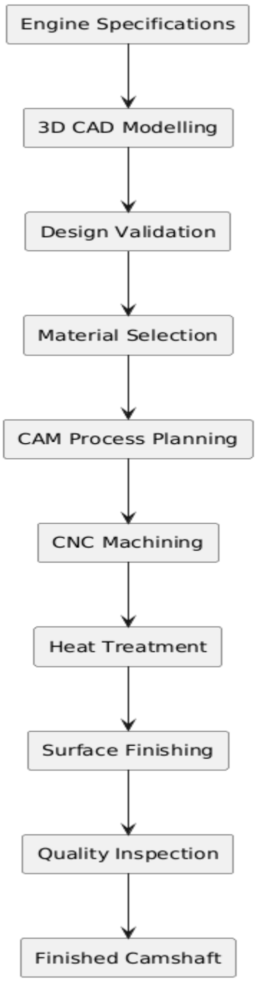

Fig1: Proposed workflow

IV. WORKING METHODOLOGY

The methodology adopted for the modelling and manufacturing of the six-cylinder engine camshaft follows a systematic engineering approach that integrates computer-aided design, material selection, machining operations, heat treatment, and dimensional inspection. The objective is to manufacture a precision camshaft capable of providing accurate valve timing, high mechanical strength, and long service life under varying engine operating conditions. The entire methodology is divided into sequential stages to ensure accuracy during both design and manufacturing while minimizing production errors and material wastage.

The first stage involves collecting the design specifications of the six-cylinder engine. Important parameters such as shaft length, base circle diameter, cam lift, journal diameter, lobe spacing, firing order, valve timing angle, and bearing dimensions are identified from standard engine design requirements. These specifications form the basis for developing an accurate camshaft model. Proper dimensional planning is essential because even a small deviation in the cam profile can affect valve timing, engine power, fuel economy, and emission performance.

After obtaining the required specifications, a three-dimensional model of the camshaft is created using CAD software such as SolidWorks or CATIA. The digital model includes the shaft body, six intake cam lobes, six exhaust cam lobes, bearing journals, keyway, and supporting features. Each cam lobe is positioned accurately according to the firing sequence of the six-cylinder engine. The CAD model enables engineers to inspect the geometry, verify clearances, and ensure dimensional consistency before manufacturing begins. Any interference between components is eliminated during this stage, thereby reducing machining errors and production costs.

Once the design is finalized, suitable engineering material is selected. Alloy steel is preferred because of its high tensile strength, wear resistance, toughness, and excellent response to heat treatment. The selected material is cut into the required length using precision cutting equipment and prepared for machining operations. Proper material selection significantly influences the durability and fatigue life of the finished camshaft, especially under repeated cyclic loading inside the engine.

The manufacturing process begins with CNC turning. During this operation, the raw cylindrical workpiece is mounted on a CNC lathe where the shaft diameter, journals, shoulders, and reference surfaces are machined according to the design dimensions. CNC turning provides excellent dimensional accuracy and ensures proper concentricity of the shaft. After turning, CNC milling is performed to generate the cam lobe profiles. CAM software converts the CAD model into machining instructions, allowing the CNC machine to accurately produce the required lobe geometry. Precision grinding is then carried out to achieve the final cam profile and improve surface finish. This operation minimizes friction between the camshaft and valve train while improving operational efficiency.

The stress acting on the camshaft due to external loading is determined using the normal stress equation:

Equation (1): Normal Stress

$$\sigma = F/A$$

Where

σ = Normal stress (MPa)

F = Applied load (N)

A = Cross-sectional area (mm^2)

The bending stress developed because of valve operating forces is calculated using:

Equation (2): Bending Stress

$$\sigma\_b = My/I$$

Where

σ_β = Bending stress (MPa)

M = Bending moment (N·mm)

y = Distance from neutral axis (mm)

I = Area moment of inertia (mm^4)

The torque transmitted through the camshaft during engine operation is evaluated using:

Equation (3): Torque Equation

$$T = (\pi/16)\tau d\^3$$

Where

T = Torque (N·mm)

τ = Shear stress (MPa)

d = Shaft diameter (mm)

These equations assist in evaluating the structural capability of the camshaft before manufacturing. The calculated values ensure that the selected material and dimensions are capable of withstanding the mechanical loads generated during continuous engine operation without failure. After the completion of machining operations, the manufactured camshaft undergoes heat treatment to improve its mechanical properties and operational durability. Since the camshaft is continuously subjected to cyclic loading, friction, and impact forces during engine operation, increasing its surface hardness is essential for extending service life. Induction hardening is selected because it produces a hard wear-resistant surface while maintaining a tough core capable of absorbing dynamic loads. During this process, the cam lobes and bearing journals are heated to the required temperature using high-frequency induction coils and are immediately quenched to obtain the desired hardness. This treatment significantly improves wear resistance, fatigue strength, and load-carrying capability without affecting the dimensional accuracy of the component.

Following heat treatment, the camshaft is subjected to precision grinding and surface finishing operations. Grinding removes the small dimensional deviations generated during heat treatment and produces an accurate cam profile with excellent surface quality. Surface finishing also minimizes friction between the cam lobes and valve followers, resulting in smoother valve operation and reduced mechanical wear. Proper surface roughness improves lubrication characteristics and prevents premature failure caused by excessive contact stresses. The finished component is thoroughly cleaned to remove machining particles, oil residues, and abrasive materials before proceeding to the inspection stage.

Dimensional inspection is carried out using precision measuring instruments such as Vernier calipers, micrometers, dial gauges, height gauges, and Coordinate Measuring Machines (CMM). Important dimensions including shaft diameter, journal diameter, cam lift, lobe spacing, concentricity, straightness, and overall length are compared with the original CAD model. Surface roughness measurements are also performed using a surface roughness tester to verify compliance with manufacturing standards. Components that satisfy all dimensional requirements proceed to the next stage, whereas defective components are re-machined or rejected. This quality control process ensures that the manufactured camshaft provides precise valve timing and reliable engine operation.

The manufactured camshaft is then evaluated for its mechanical performance. The rotational speed of the camshaft is determined from the engine speed using the angular velocity equation.

Equation (4): Angular Velocity

$$\omega = 2\pi N/60$$

Where

ω = Angular velocity (rad/s)

N = Rotational speed (rpm)

This equation determines the rotational motion of the camshaft during engine operation and assists in evaluating valve timing performance. The mechanical power transmitted through the camshaft is calculated using the following equation.

Equation (5): Power Transmission

$$P = \frac{2\pi NT}{60}$$

Where

P = Power transmitted (W)

N = Rotational speed (rpm)

T = Torque (N·m)

The transmitted power indicates the capability of the camshaft to transfer mechanical energy from the crankshaft to the valve train with minimum power loss. Accurate power transmission is essential for maintaining engine efficiency and proper combustion.

The structural safety of the manufactured camshaft is finally verified using the factor of safety equation.

Equation (6): Factor of Safety

$$FOS = \sigma\_y/\sigma\_w$$

Where

σ_Y = Yield strength of the material (MPa)

σw = Working stress acting on the camshaft (MPa)

The factor of safety ensures that the operating stress remains well below the allowable material strength, thereby preventing mechanical failure during long-term engine operation. A higher factor of safety indicates greater reliability and improved service life under varying loading conditions. After completing the analytical calculations, the final manufactured camshaft is assembled with the engine valve train to verify its functional performance. Proper synchronization between the camshaft and crankshaft is checked to ensure accurate opening and closing of the intake and exhaust valves according to the specified firing order of the six-cylinder engine. Smooth rotation of the shaft, proper engagement of the cam lobes, and absence of abnormal vibration or excessive noise confirm the success of the manufacturing process.

The final validation stage compares the manufactured dimensions with the original CAD model and design specifications. The measured values are recorded and analyzed to determine dimensional deviations and manufacturing accuracy. If all measured parameters remain within the acceptable tolerance limits, the camshaft is approved for engine installation. The proposed methodology therefore integrates digital modelling, CNC machining, heat treatment, precision grinding, quality inspection, and performance verification into a unified manufacturing framework. This systematic approach improves dimensional accuracy, minimizes production errors, enhances mechanical reliability, reduces manufacturing cost, and ensures the production of a durable six-cylinder engine camshaft suitable for modern automotive applications.

V. IMPLEMENTATION

The implementation of the Modelling and Manufacturing of a Six-Cylinder Engine Camshaft project involves a systematic sequence of design, material preparation, machining, heat treatment, finishing, inspection, and functional validation. The implementation aims to manufacture a precision camshaft that satisfies the dimensional and mechanical requirements of a six-cylinder internal combustion engine. Modern Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), and Computer Numerical Control (CNC) machining technologies are integrated throughout the implementation process to improve manufacturing accuracy, reduce production time, and enhance product reliability. Every stage is executed according to engineering standards to ensure that the manufactured camshaft provides accurate valve timing, improved wear resistance, and long operational life.

The implementation begins with the preparation of the three-dimensional camshaft model using CAD software such as SolidWorks, CATIA, or Autodesk Inventor. The complete geometry of the camshaft is developed according to the design specifications of a six-cylinder engine. The model consists of the shaft body, intake and exhaust cam lobes, bearing journals, keyway, and support sections. Each cam lobe is positioned according to the firing order and valve timing sequence to ensure synchronized valve operation. The CAD model undergoes dimensional verification to confirm that all critical dimensions including shaft diameter, journal spacing, cam lift, and lobe profile comply with the design requirements. The validated digital model serves as the reference for all subsequent manufacturing operations.

After completing the CAD model, the design is transferred to Computer-Aided Manufacturing software to generate machining tool paths. CAM software converts the three-dimensional geometry into CNC machine instructions using standard G-code. The machining sequence, cutting tools, spindle speed, feed rate, depth of cut, and machining strategy are carefully selected to maximize production efficiency while maintaining dimensional accuracy. Virtual machining simulation is performed before actual production to detect tool interference, collision, or programming errors. This preliminary verification minimizes machining defects and improves manufacturing productivity.

The next implementation stage involves selecting an appropriate raw material. Alloy steel is chosen because of its excellent mechanical strength, hardness, fatigue resistance, and machinability. The raw cylindrical bar is inspected visually to ensure that it is free from cracks, surface defects, and dimensional irregularities. The material is then cut into the required length using a precision band saw. Both ends of the workpiece are faced to obtain smooth reference surfaces before machining. Proper material preparation ensures stable clamping during machining operations and improves manufacturing accuracy. The first machining operation is CNC turning. The prepared workpiece is mounted on a CNC lathe where the outer diameter, bearing journals, shoulders, and shaft body are machined according to the design dimensions. Multiple roughing passes remove excess material, followed by finishing passes that produce accurate diameters and smooth surface quality. CNC turning ensures high concentricity between journals and minimizes dimensional variation. The machined shaft is inspected periodically using micrometers and Vernier calipers to verify compliance with dimensional tolerances.

Following turning operations, the partially machined shaft is transferred to a CNC milling machine for cam lobe machining. The generated CAM program controls the movement of the cutting tool to produce the required cam profiles accurately. Each intake and exhaust lobe is machined individually while maintaining the specified angular relationship between adjacent lobes. High-precision milling ensures that the valve lift, opening duration, and timing characteristics remain consistent throughout the camshaft. Continuous coolant supply is maintained during machining to prevent excessive tool wear and thermal distortion.

After milling, precision grinding is carried out to obtain the final cam profile and improve surface finish. Grinding removes small machining marks left during milling and produces the required dimensional accuracy for the cam lobes and bearing journals. High-quality grinding significantly reduces friction between the camshaft and valve followers while improving lubrication conditions. Proper surface finish also minimizes mechanical wear and increases the service life of the valve train components. The finished cam profile is compared with the original CAD geometry to verify profile accuracy.

Heat treatment is then implemented to enhance the mechanical properties of the manufactured camshaft. Induction hardening is selected because it increases surface hardness while maintaining a tough core structure capable of absorbing repeated dynamic loading. During induction hardening, the cam lobes and journals are rapidly heated to the required temperature using electromagnetic induction and are immediately quenched. This process improves wear resistance, fatigue strength, and load-carrying capacity without introducing significant dimensional distortion. After heat treatment, stress-relieving operations are performed when necessary to eliminate residual stresses generated during machining and hardening.

Surface finishing operations are subsequently carried out to improve the appearance and functional quality of the camshaft. Fine polishing removes minor surface imperfections and enhances lubrication characteristics during engine operation. The polished surfaces reduce frictional losses and improve contact conditions between the camshaft and valve train components. Proper cleaning is performed to remove grinding particles, cutting fluids, and contaminants before quality inspection.

Quality inspection represents one of the most critical implementation stages. Dimensional verification is performed using Vernier calipers, micrometers, dial gauges, height gauges, and Coordinate Measuring Machines (CMM). Important parameters including shaft diameter, journal diameter, cam lift, lobe spacing, shaft straightness, concentricity, and overall length are measured accurately. Surface roughness is evaluated using a surface roughness tester to ensure compliance with engineering specifications. Hardness testing is also conducted after heat treatment to verify that the required surface hardness has been achieved. Components failing to satisfy dimensional or mechanical requirements are rejected or reworked before final assembly.

The completed camshaft is finally assembled with the valve train for functional verification. Manual rotation tests are performed to ensure smooth movement without excessive vibration or interference. The opening and closing of intake and exhaust valves are examined carefully to confirm accurate valve timing. Proper synchronization between the camshaft and crankshaft ensures efficient combustion, improved fuel economy, and reliable engine operation. Functional testing also confirms that the manufactured component satisfies the intended performance requirements under simulated operating conditions.

The implementation results demonstrate that integrating CAD modelling, CAM programming, CNC machining, precision grinding, heat treatment, and quality inspection provides a reliable manufacturing framework for producing high-quality six-cylinder engine camshafts. The adopted implementation approach minimizes production errors, improves dimensional consistency, reduces manufacturing cost, and enhances product reliability. The use of modern manufacturing technologies enables the production of durable camshafts with superior wear resistance, accurate valve timing, and long service life. Consequently, the implemented methodology provides an effective solution for manufacturing precision automotive engine components capable of meeting the performance requirements of modern internal combustion engines.

VI. RESULTS EXPLANATIONS

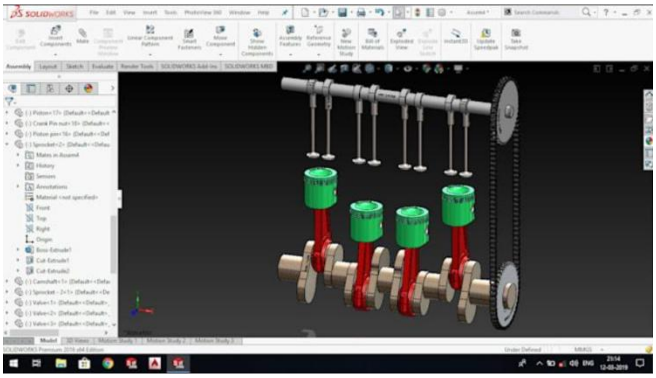

Fig.2 3D CAD Model of Six-Cylinder Engine Camshaft

The three-dimensional CAD model represents the complete geometry of the six-cylinder engine camshaft developed using Computer-Aided Design software. The model includes the shaft body, bearing journals, keyway, and twelve cam lobes corresponding to the intake and exhaust valves of the six-cylinder engine. Dimensional verification performed within the CAD environment confirmed that all geometric parameters satisfied the specified design requirements. The digital model enabled visualization of the complete assembly before manufacturing and helped identify potential dimensional conflicts or interference between adjacent cam lobes. The use of CAD significantly reduced design modifications during production and improved overall manufacturing accuracy. The finalized model served as the master reference for generating CNC machining tool paths and quality inspection data.

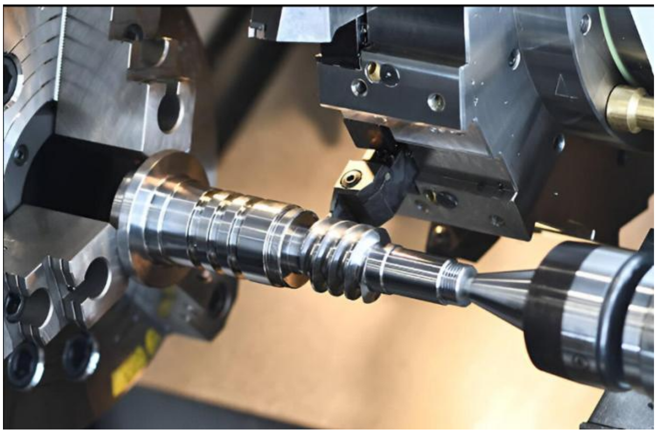

Fig. 2 CNC Machining of Camshaft

The CNC machining process successfully produced the shaft body, journals, and cam lobes according to the generated CAM program. The turning operation accurately machined the shaft diameter and bearing journals, while CNC milling produced the required cam lobe profiles with high dimensional precision. Continuous coolant supply maintained machining stability and minimized thermal distortion during cutting. Dimensional measurements taken after machining indicated that all critical dimensions remained within the specified tolerance limits. The implementation of CNC technology significantly reduced machining errors and improved repeatability compared with conventional machining methods. The generated cam profiles closely matched the original CAD geometry, demonstrating the effectiveness of computer-controlled manufacturing.

Fig. 3 Heat-Treated Camshaft Surface

After machining, the camshaft underwent induction hardening to improve its surface hardness and wear resistance. Hardness measurements confirmed a significant increase in surface strength while maintaining adequate core toughness. The heat treatment process successfully enhanced the mechanical properties of the cam lobes and bearing journals without producing noticeable dimensional distortion. Improved hardness increases resistance to wear caused by continuous contact between the cam lobes and valve followers. The treated camshaft therefore exhibits greater fatigue resistance and longer operational life under repeated engine loading. The results verify that induction hardening is an effective method for improving the durability of automotive camshafts.

Fig. 4 Coordinate Measuring Machine (CMM) Inspection

Precision inspection was performed using Vernier calipers, micrometers, and Coordinate Measuring Machines (CMM) to verify the dimensional accuracy of the manufactured camshaft. Critical dimensions including shaft diameter, journal diameter, cam lift, lobe spacing, concentricity, and overall length were measured and compared with the CAD model. The inspection results indicated that all measured values remained within the allowable manufacturing tolerances. Surface roughness measurements also confirmed that the grinding process produced a smooth finish suitable for engine applications. The dimensional consistency obtained during inspection demonstrates the reliability of the adopted manufacturing process.

VII. CONCLUSION

The present work successfully demonstrated the modelling and manufacturing of a six-cylinder engine camshaft using modern Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) techniques integrated with precision machining processes. A three-dimensional model of the camshaft was developed according to standard engine design specifications, including the shaft body, bearing journals, intake and exhaust cam lobes, and keyway. The CAD model enabled accurate dimensional verification and design validation before manufacturing, thereby minimizing design errors and reducing the need for repeated prototype development. The digital modelling approach also improved production planning and ensured that the generated machining data accurately represented the intended camshaft geometry.The manufacturing process incorporated CNC turning, CNC milling, precision grinding, heat treatment, surface finishing, and dimensional inspection to produce a high-quality engine component. Precision machining ensured accurate cam profiles, journal diameters, and shaft alignment, while induction hardening significantly improved the surface hardness, wear resistance, and fatigue strength of the camshaft. Comprehensive quality inspection confirmed that all critical dimensions remained within the specified engineering tolerances. The finished component demonstrated excellent dimensional accuracy, smooth surface finish, and reliable mechanical characteristics suitable for long-term engine operation.The overall implementation confirmed that integrating CAD modelling with advanced manufacturing technologies improves production efficiency, product consistency, and manufacturing accuracy while reducing material waste and production cost. The developed six-cylinder engine camshaft is capable of providing precise valve timing, improved fuel efficiency, reduced mechanical wear, and enhanced engine reliability. The proposed methodology offers an economical and systematic approach for manufacturing precision automotive engine components and can be applied to various internal combustion engine configurations. Future work may focus on finite element stress analysis, dynamic performance evaluation, lightweight material selection, and automated manufacturing systems to further improve camshaft performance, durability, and production efficiency in next-generation automotive applications.

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