

	الجمهورية الجزائرية الديمقراطية الشعبية	
	People's Democratic Republic of Algeria	
	وزارة التعليم العالي والبحث العلمي	
	Ministry of Higher Education and Scientific Research	
	جامعة عبد الحميد بن باديس - مستغانم	
	Abdel Hamid Ibn Badis University - Mostaganem	
	كلية العلوم والتكنولوجيا	
	Faculty of Sciences and Technology	
قسم هندسة ميكانيكية		
	Department of Mechanical Engineering	

N° d'ordre : M2...../GM/2025

## FINAL THESIS FOR ACADEMIC MASTER'S DEGREE

**Industry: Mechanical engineering**

**Specialty : Mechanical construction**

### Theme

**Study of variable valve timing for an internal  
combustion engine**

Presented by :

-BOUCHAREB ABDELILLAH      -BENSIDAOUI CHEMSS EDDINE

Supported on 28/09/ 2025 before the jury composed of:

president	ZENASNI Ramdane	Professor	University of mostaganem
examiner	BENAISSA Mohamed	assistant professor	University of mostaganem
Supervisor	BENDOUKHA Mohammed	Doctor	University of mostaganem

Academic year 2024/2025

## **Signings (Dédicaces)**

We dedicate this work to our beloved parents, whose endless love, sacrifices, and unwavering support have been the foundation of our education and personal growth. Without their guidance and encouragement, none of this would have been possible. We also extend this dedication to our brothers and sisters, for their constant encouragement, patience, and understanding during the most challenging times of our journey. To our friends, who have always motivated us, shared in our struggles, and stood by our side with kindness and support, we owe deep gratitude. Finally, this work is dedicated to all those who believed in us, inspired us, and gave us the strength and determination to pursue and achieve this goal.

## **Acknowledgments (Remerciements)**

We would like to express our deepest gratitude to our supervisor, **[BENDOUKHA Mohammed]**, for his valuable guidance, insightful advice, and constant support throughout the completion of this work. His expertise and encouragement have been essential in helping us overcome difficulties and achieve our objectives. We also extend our sincere thanks to the faculty members of the Department of Mechanical Engineering at **Abdelhamid Ibn Badis University – Mostaganem**, for the quality of their teaching and for providing us with the knowledge and tools necessary to carry out this research. Our heartfelt appreciation also goes to our colleagues and friends, who have supported us with their collaboration, motivation, and kindness during this journey. Finally, we wish to express our deepest gratitude to our families, whose unconditional love, patience, and encouragement have been the driving force behind all our efforts and the successful completion of this thesis.

# List of figures

<b>Figure 1</b> Turbocharged internal combustion engine – 3D rendered model.[2].....	- 2 -
<b>Figure 2</b> A simplified schematic of a combustion process [3].....	- 4 -
<b>Figure 3</b> P-V and T-S Diagram of Otto cycle [3] .....	- 5 -
<b>Figure 4</b> P-V and T-S Diagram of Diesel cycle [3].....	- 6 -
<b>Figure 5</b> "four stroke engine parts" [3].....	- 7 -
<b>Figure 6</b> Crankshaft [3]. .....	- 8 -
<b>Figure 7</b> Piston [4].....	- 9 -
<b>Figure 8</b> Camshaft [6].....	- 12 -
<b>Figure 9</b> Engine valves [8]. .....	- 13 -
<b>Figure 10</b> Toothed timing belt [9] .....	- 14 -
<b>Figure 11</b> Technical image of a 4-cylinder engine showing camshaft, crankshaft, pistons, valves, and timing belt components [10]. .....	- 15 -
<b>Figure 12</b> Renault K4M 1.6L engine [14].....	- 16 -
<b>Figure 13</b> vehicle Dacia Sandero I Stepway [18].....	- 19 -
<b>Figure 14</b> VVT system [25].....	- 22 -
<b>Figure 15</b> VVL system [25].....	- 23 -
<b>Figure 16</b> VVT vs VVL systems [25]. .....	- 24 -
<b>Figure 17</b> Camshaft modeled in SolidWorks [40].....	- 28 -
<b>Figure 18</b> Cam modeled in SolidWorks [40]. .....	- 28 -
<b>Figure 19</b> Rocker modeled in SolidWorks [40]. .....	- 29 -
<b>Figure 20</b> actuator modeled in SolidWorks [40].....	- 30 -
<b>Figure 21</b> camshaft position sensor modeled in SolidWorks [40]. .....	- 30 -

<b>Figure 22</b> intake and exhaust cam graph .....	- 34 -
<b>Figure 23</b> Cam profile design obtained with MATLAB .....	- 34 -
<b>Figure 24</b> VVT cam design obtained with MATLAB .....	- 34 -
<b>Figure 25</b> VVT cam graph.....	- 34 -
<b>Figure 26</b> power rating range . .....	- 42 -
<b>Figure 27</b> main toothed belt dimensions. ....	- 43 -
<b>Figure 28</b> Wrap angle . .....	- 46 -
<b>Figure 29</b> cam phaser [38].....	- 50 -
<b>Figure 30</b> Cam phaser modeled in SolidWorks [40].....	- 51 -
<b>Figure 31</b> oil flow in the cam phaser adjusts the camshaft position [40].....	- 52 -
<b>Figure 32</b> Phaser modeled in SolidWorks [40]. ....	- 53 -
<b>Figure 33</b> Conceptual design of variable valve timing distribution system [40].....	- 55 -
<b>Figure 34</b> Another view, Conceptual design of variable valve timing distribution system [40]..	- 56 -
<b>Figure 35</b> admission cam mechanism [40].....	- 59 -
<b>Figure 36</b> Engine Tachometer Display (x1000 RPM) [41]. ....	- 60 -
<b>Figure 37</b> cam profile #1 under working order [40].....	- 60 -
<b>Figure 38</b> Accelerating [40] [43]. ....	- 60 -
<b>Figure 39</b> Sensor placements and types [40].....	- 61 -
<b>Figure 40</b> OIL unit controller [40]. ....	- 62 -
<b>Figure 41</b> overview of the workarounds of the actuator and fork assembly [40]. ....	- 63 -
<b>Figure 42</b> cam profile #2 under working order [40].....	- 64 -
<b>Figure 43</b> Support [40]. ....	- 65 -
<b>Figure 44</b> mesh [44]. ....	- 67 -
<b>Figure 45</b> fixed ground boundary condition[44]. ....	- 68 -
<b>Figure 46</b> reevaluate boundary condition [44]. ....	- 68 -

**Figure 47** contact region boundary condition [44]...... - 69 -

**Figure 48** Static structural boundary condition [44]...... - 70 -

**Figure 49** total deformation simulation and result [44]...... - 71 -

**Figure 50** von-misses stress simulation and result [44]. ..... - 72 -

**Figure 51** shear stress simulation and result[44]. ..... - 73 -

# List of tables

**Table 1** Functional and Technical Parameters of K7M800..... - 17 -

**Table 2** system componant and materials..... - 58 -

# List of abbreviations

TDC : Top Dead Center

ICE : internal combustion engine

ECU : engine contrôle unit

CPU : Central Processing Unit

EGR: Exhaust Gas Recirculation

Rpm : tr/min

VVT: variable valve timing

VVL: variable valve lift

VTEC : Variable Valve Timing & Lift Electronic Control

EIVC: Early Inlet Valve Closing

LIVC: Late Inlet Valve Closing

$\eta_b$ : brake thermal efficiency

$G_n$ : fuel mass flow rate (fuel consumption per unit time)

BSFC: Brake Specific Fuel Consumption

$c_s$ : Consommation spécifique effective (Specific fuel consumption, same idea as BSFC).

$G_p$  indicated specific fuel consumption

BMEP: Brake Mean Effective Pressure

# Résumé

## **In English :**

This thesis focus on the study and development of a Variable Valve Timing (VVT) distribution system applied to the Renault K7M800 engine. The main goal of the system is to improve energy efficiency, increase the power output, and reduce pollutant emissions in comparison to a regular fixed-timing system.

First presented, were the internal combustion engine generally, and traditional distribution systems generically; discussing drawbacks in terms of their performance and environmental requirements, followed by a discussion of different cam profiles and variable valves technologies that illustrated the benefits of both VVT and Variable Valve Lift (VVL) systems, for cylinder filling improvement and reductions of fuel specific consumption.

Second, a dimensioning study was conducted on the principal dimensions of the component pieces: timing belt; camshaft; cam phaser; allowing a mechanical validation of the system to be offered and create definitions for the isolated parameters of usage to guarantee proper functioning of the VVT system.

Concluding with a numerical simulation study that will analyze the real impacts of variable timing on the behavior of the engine evaluation, making some inferences as it relates to performance, consumption, and emissions after system implementation.

**Keywords:** Internal combustion engine, Valve timing, VVT, Camshaft, Cam, Dimensioning, Simulation.

## **In French:**

Ce mémoire porte sur l'étude et le développement d'un système de distribution à calage variable (VVT) appliqué au moteur Renault K7M800. L'objectif principal est d'améliorer le rendement énergétique, la puissance et de réduire les émissions polluantes par rapport à un système de distribution classique à calage fixe.

Dans un premier temps, une présentation générale des moteurs à combustion interne et du système de distribution traditionnel a permis d'identifier les limites techniques et environnementales de ce dernier. Par la suite, l'étude des profils de cames et des différents mécanismes de distribution variable a mis en évidence l'intérêt des systèmes VVT et VVL dans l'optimisation du remplissage des cylindres et la réduction de la consommation spécifique.

Un travail de dimensionnement a ensuite été réalisé sur les principaux organes du système étudié, notamment la courroie crantée, l'arbre à cames et le cam phaser. Les calculs menés ont permis de vérifier la faisabilité mécanique de l'intégration du système et de définir les paramètres nécessaires pour assurer son bon fonctionnement.

Enfin, une étape de simulation numérique sera entreprise afin d'analyser l'impact réel du calage variable sur le comportement du moteur et de quantifier les gains en termes de performance, de consommation et d'émissions.

**Mots-clés** : Moteur à combustion interne, Distribution, VVT, arbre a came, came, Dimensionnement, Simulation.

## In arabic :

تركز هذه الأطروحة على دراسة وتطوير نظام توزيع توقيت الصمام المتغير (VVT) المطبق على محرك رينو K7M800. الهدف الرئيسي هو تحسين كفاءة الطاقة وزيادة إنتاج الطاقة وتقليل انبعاثات الملوثات مقارنة بنظام التوقيت الثابت التقليدي.

أولاً، أبرز عرض عام لمحركات الاحتراق الداخلي وأنظمة التوزيع التقليدية القيود من حيث الأداء والمتطلبات البيئية. ثم أظهرت دراسة ملامح الكامات وآليات الصمامات المتغيرة المختلفة فوائد أنظمة VVT و VVL في تحسين ملء الأسطوانات وتقليل استهلاك الوقود المحدد.

أجريت دراسة أبعاد للمكونات الرئيسية للنظام، بما في ذلك حزام التوقيت وعمود الكامات ومغير توقيت الكامات. أثبتت الحسابات الجدوى الميكانيكية للحل المقترح وحددت المعلمات المطلوبة للتشغيل السليم.

أخيراً، سيتم إجراء مرحلة محاكاة رقمية لتحليل التأثير الحقيقي للتوقيت المتغير على سلوك المحرك ولتحديد المكاسب المتوقعة من حيث الأداء والاستهلاك والانبعاثات.

**الكلمات المفتاحية:** محرك احتراق داخلي، توزيع، VVT، عمود الكامات، الكامات، تحديد الأبعاد، المحاكاة.

# Table des matières

Signings (Dédicaces).....	ii
Acknowledgments (Remerciements) .....	iii
List of figures .....	iv
List of tables .....	vii
List of abbreviations.....	viii
Résumé .....	ix
General introduction.....	- 1 -
Chapter I :.....	- 2 -
I.1    Introduction .....	- 2 -
I.2    Operating principle :.....	- 3 -
I.3    Thermodynamic Cycle of an Internal Combustion Engine (MCI):.....	- 4 -
I.3.1    Fundamental Thermodynamic Properties of ICE Cycles.....	- 4 -
I.3.2    Common Thermodynamic Cycles for MCI:.....	- 5 -
I.4    Internal combustion engine systems:.....	- 6 -
I.4.1    Crank connecting rod system: .....	- 7 -
I.4.2    Cooling system: .....	- 9 -
I.4.3    Power Supply System:.....	- 10 -
I.5    The distribution system : .....	- 11 -
I.5.1    Distribution system component :.....	- 12 -
I.5.2    Description of K7M800 (engine): .....	- 16 -

I.5.3	Conclusion:.....	- 19 -
<b>Chapter II : Design and Development of Cam Profiles .....</b>		<b>- 20 -</b>
II.1	Introduction .....	- 20 -
II.2	Variable Valve Timing Systems:.....	- 20 -
II.2.1	Objective: .....	- 21 -
II.2.2	Mechanism of VVT:.....	- 21 -
II.2.3	The different types of variable distribution:.....	- 22 -
II.2.4	Choice of distribution type: .....	- 25 -
II.2.5	Description of VVL elements:.....	- 27 -
II.2.6	Cam theory and role: .....	- 31 -
II.2.7	Application of Cam Theory using MATLAB: .....	- 33 -
II.3	Conclusion : .....	- 35 -
<b>Chapter III : Belt and Cam phaser Dimensioning.....</b>		<b>- 36 -</b>
III.1	Advantages of the variable system compared to the conventional system and the energy gain of a variable valve timing (VVT) engine compared to a conventional valve timing engine:-	36 -
III.1.1	The advantages: .....	- 36 -
III.1.2	The energy gain of a variable valve timing (VVT) engine compared to a conventional valve timing engine:.....	- 38 -
III.2	Dimensioning of variable distribution components: .....	- 40 -
III.2.1	Timing belt [6]:.....	- 40 -
	Calculs: .....	- 40 -
III.2.2	Camshaft dimensioning:.....	- 50 -

III.3	Cam phaser: .....	- 50 -
III.3.1	Description of cam phaser: .....	- 50 -
III.3.2	Front view of cam phaser : .....	- 53 -
III.4	Conclusion : .....	- 54 -
<b>Chapter IV : Simulation .....</b>		<b>- 55 -</b>
IV.1	Descreption of the system: .....	- 55 -
IV.1.1	Systeme component:.....	- 57 -
IV.2	Support : .....	- 65 -
IV.3	Code : .....	- 66 -
IV.4	MESH (Maillage) : .....	- 67 -
IV.5	Boundary conditions:.....	- 68 -
IV.6	Result and intervention :.....	- 71 -
IV.6.1	Total Deformation : .....	- 71 -
IV.6.2	Equivalent Stress (von Mises):.....	- 72 -
IV.6.3	Maximum Shear Stress:.....	- 73 -
IV.7	Conclusion:.....	- 74 -
<b>General conclusion and recommendation .....</b>		<b>- 75 -</b>
<b>Bibliography.....</b>		<b>- 78 -</b>

## General introduction

The optimization of internal combustion engines (ICEs) has long been a focus of automotive engineering, driven by the need for greater efficiency and performance. Among the most significant advancements in this field are variable timing systems, which dynamically adjust valve timing and lift to optimize engine performance across a wide range of operating conditions. Examples like Variable Valve Timing (VVT) and Variable Valve Timing and Lift Electronic Control (VTEC) illustrate the transformative potential of these systems. For small-cylinder engines, which are increasingly favored in compact cars due to their lightweight design and fuel efficiency, variable timing systems are particularly vital. They address the inherent limitations of fixed valve timing, enabling small engines to deliver both low-end torque and high-end power without compromising efficiency.

Variable timing systems enhance engine performance by optimizing airflow and combustion efficiency, reducing pumping losses at low speeds, and enabling aggressive performance at high speeds. These systems are essential for small-displacement engines to achieve competitive power output while maintaining superior fuel economy.

This thesis explores the engineering principles behind variable timing systems, their application in small-cylinder engines, and their impact on overall performance. By examining their role in addressing the unique challenges of small engines, this study seeks to answer: Why are variable timing systems crucial for enhancing the performance of modern thermal engines, and how do they address the fundamental trade-offs between efficiency, power, and emissions?

## Chapter I :

# Generalities general information about the internal combustion engine

### I.1 Introduction

Internal combustion engines are thermal fluid machines: the combustion of a mixture of air and fuel generates mechanical energy. All the working processes occur in a working space called a working cylinder. Because the force/energy in the cylinder is transferred through a variable volume, internal combustion engines are volumetric prime movers.

These engines are often used to power vehicles, boats or locomotives. Internal combustion engines are also commonly used to power drives that need to run reliably at all times, and are not reliant on the electricity grid; in other words, emergency generators or prime movers in construction or agriculture. Small, single-cylinder engines are a great way of explaining basic principles of engine technology [1].



**Figure 1** Turbocharged internal combustion engine – 3D rendered model.[2]

## I.2 Operating principle :

In 1862, BEAU DE ROCHAS, a Frenchman, suggested taking advantage of the process described below for gaseous states in a piston engine. The complete cycle consists of 4 strokes of the piston and, therefore, 2 revolutions of the crankshaft.

- **Admission:** The intake valve is open and the exhaust valve closed. The piston moves down (B.D.C.), and as a result, the mixture (or air in the case of a diesel engine) is sucked directly from the intake manifold [4].
- **Compression:** Both valves are closed; at this point, the piston raises, and the gases are compressed. This makes the air or mixture rise in temperature to a point that causes an explosion to happen [4].
- **Combustion and expansion:** Just before TDC, an electric spark initiates combustion returns the piston to TDC.

The increase in pressure on the piston creates a force on the connecting rod, and thus a driving torque on the crankshaft [4].

- **The exhaust:** The piston arrives at the end of the expansion stroke and the bottom of the cylinder (P.M.B.), and rises once more. After the exhaust valve has been opened, the burnt gases can escape down the exhaust manifold [4].

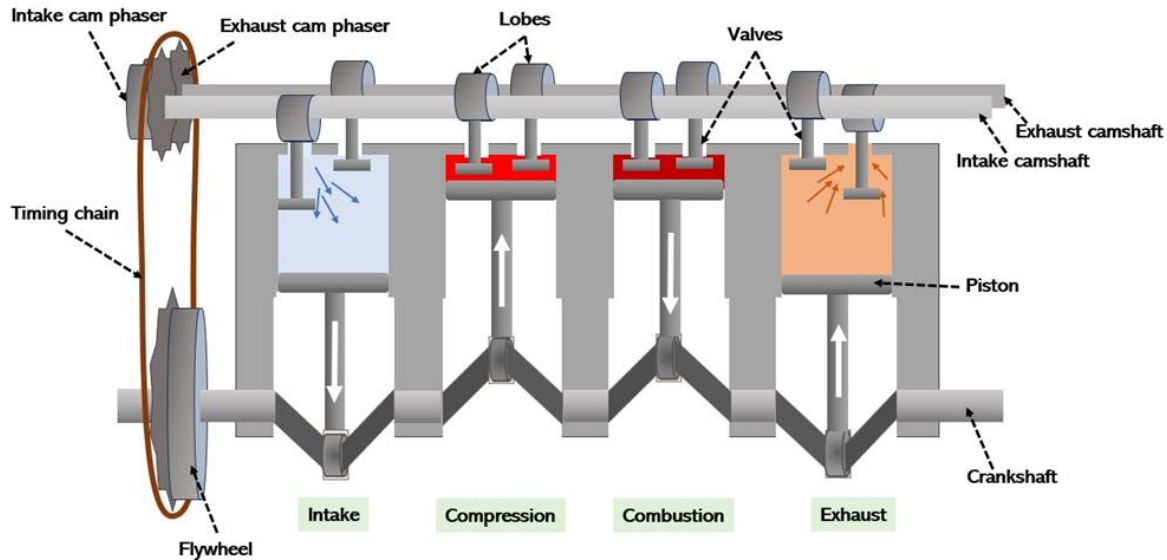


Figure 2 A simplified schematic of a combustion process [3].

### I.3 Thermodynamic Cycle of an Internal Combustion Engine (MCI):

A thermodynamic cycle is a series of thermodynamic processes that are connected by heat and work entering and leaving such that the system returns to its original state. In terms of internal combustion engine (ICE) processes, we can view cycles in terms of how the working fluids (air-fuel mixture and combustion gases) assume the various steps of compression, combustion, expansion, and exhaust to convert chemical energy into mechanical work.

#### I.3.1 Fundamental Thermodynamic Properties of ICE Cycles

The working fluid is typically modeled as an ideal gas with constant specific heat capacities and composition.

Compression and expansion processes are generally adiabatic (no heat transfer).

Heat addition (combustion in most cases) and rejection are state points at constant volume or constant pressure, depending on the specific cycle.

Since the cycle is closed, the state of the working fluid returns to its original thermodynamic state after one complete cycle.

Mechanical losses, gas-dynamic losses, and radiation losses are often ignored in idealized cycles, which creates simplicity.

### I.3.2 Common Thermodynamic Cycles for MCI:

#### I.3.2.1 Otto Cycle (Spark Ignition Engine):

The Otto cycle is the idealized thermodynamic cycle for spark ignition engines, commonly used in gasoline engines. It consists of four main processes:

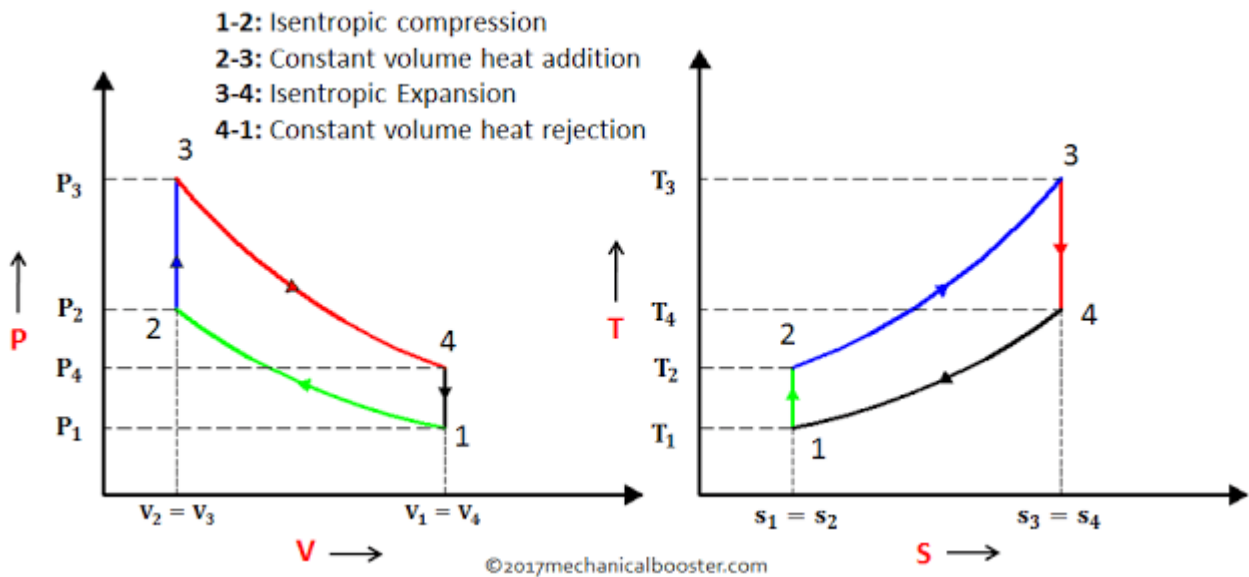


Figure 3 P-V and T-S Diagram of Otto cycle [3] .

1 → 2: Adiabatic (isentropic) compression: The piston compresses the air-fuel mixture, increasing pressure and temperature while volume decreases.

2 → 3: Constant volume heat addition: Combustion occurs rapidly at nearly constant volume, causing a sharp rise in pressure and temperature.

3 → 4: Adiabatic (isentropic) expansion: The high-pressure gases expand, pushing the piston and doing work on it. Pressure and temperature decrease as volume increases.

4 → 1: Constant volume heat rejection: Exhaust gases are expelled, and the system returns to initial state.

### I.3.2.2 Diesel Cycle (Compression Ignition Engine) :

The Diesel cycle is typical for compression ignition engines, with a key difference being that heat addition occurs at constant pressure rather than constant volume:

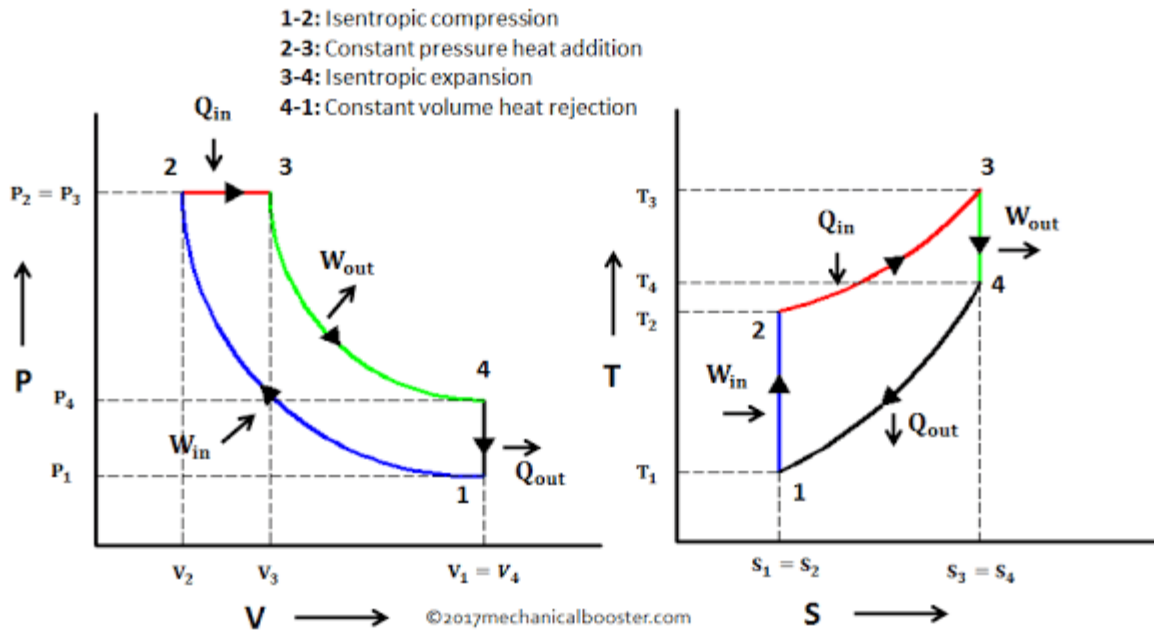


Figure 4 P-V and T-S Diagram of Diesel cycle [3].

1 → 2: Isentropic compression: Air is compressed adiabatically, increasing pressure and temperature.

2 → 3: Constant pressure heat addition: Fuel is injected and combusted, increasing volume and temperature at constant pressure.

3 → 4: Isentropic expansion: Hot gases expand adiabatically, performing work.

4 → 1: Constant volume heat rejection: Exhaust gases are expelled, returning to initial state.

## I.4 Internal combustion engine systems:

In addition, the internal combustion engine is made up of several large parts, including:

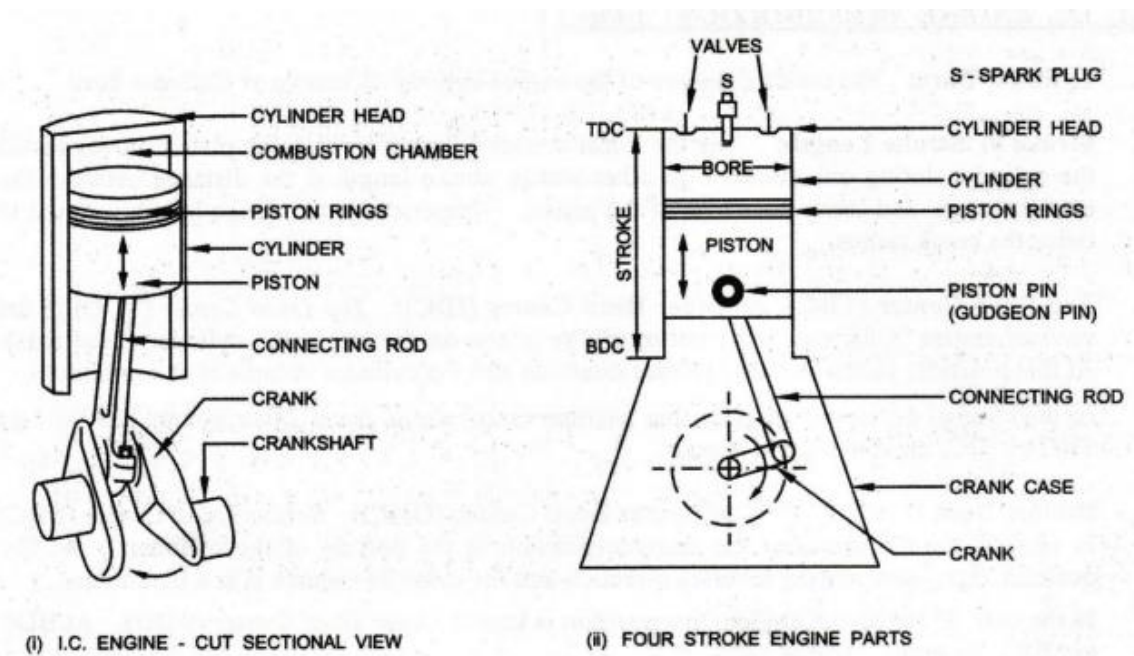
## I.4.1 Crank connecting rod system:

The crank connecting rod system found in an internal combustion engine (ICE) is an important mechanical assembly that converts the reciprocating linear motion of the piston into the rotary motion of the crankshaft, and thus ongoing power delivery is possible.

### I.4.1.1 Connecting Rod:

The connecting rod, also known as a "con rod," connects the piston to the crankshaft. It has two ends:

- ❖ **The small end** connects to the piston through the gudgeon pin (known as the wrist pin or piston pin). This allows rotation of the piston and rod.
- ❖ **The big end** connects to the crankpin of the crankshaft. This connection will typically consist of a plain bearing connection to minimize friction. Smaller engines may have rolling-element bearings instead.



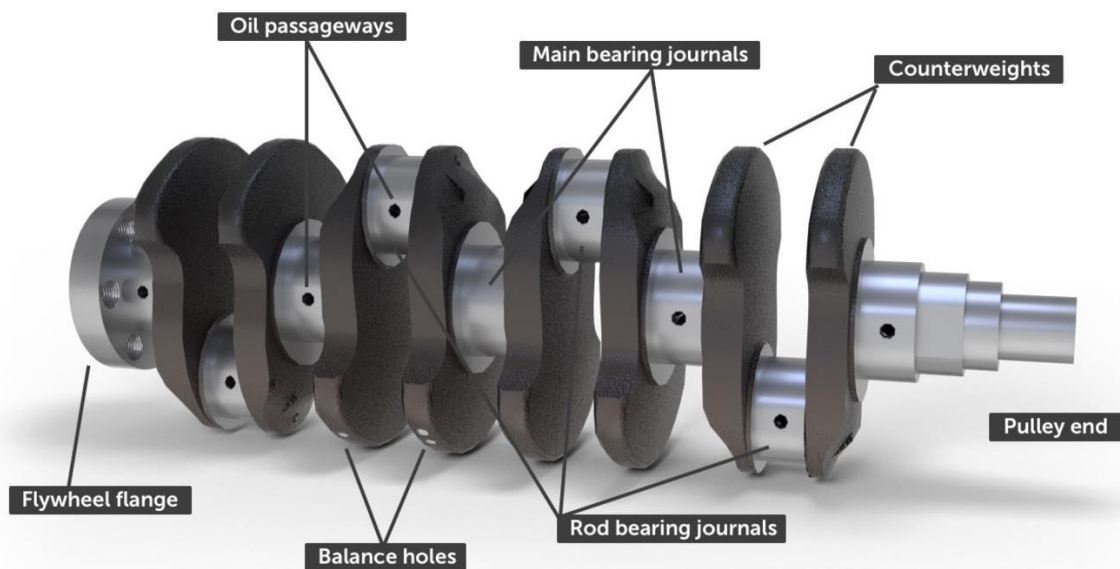
**Figure 5** "four stroke engine parts" [3].

### I.4.1.2 Crankshaft:

The crankshaft is a critical part of an internal combustion engine. It is a shaft that rotates and converts the linear motion of the piston into rotary motion.

The crankshaft connects to the pistons via connecting rods, which convey the force created by the piston to the crankshaft. The crankshaft typically consists of a central shaft with a number of crankpins which extend outward at a given angle to connect with the piston connecting rods. The crankshaft's rotary motion is used to drive the mechanical instruments connected with the engine, such as the transmission, water pump, oil pump and camshaft.

The lengths and diameter of the crankshaft pins are significant because they determine the piston stroke and the amount of power that can be created by the engine. In general, more piston stroke means more power.



**Figure 6** Crankshaft [3].

### **I.4.1.3 Piston:**

A component of the combustion engine, the piston is responsible for transforming the energy released during combustion into mechanical work, and transmitting it in the form of rotational force to the crankshaft via the piston pin and connecting rod.



**Figure 7** Piston [4].

The piston moves up and down inside the cylinder during the engine cycle. The connecting rod transmits this linear motion to the crankshaft. While the small end follows the piston's linear motion, the big end moves in a circular path around the crankshaft journal. This causes the connecting rod to swing and change its inclination throughout the cycle. The crankshaft then rotates, delivering power to the drivetrain and other engine accessories.

### **I.4.2 Cooling system:**

The cooling system in the internal combustion engine (ICE) is vital to maintain operating temperature, avoid overheating, and to promote efficiency and long life for engine components.

There is two of types cooling system:

### **I.4.2.1 Water (Liquid) Cooling System:**

The standard system in modern ICEs. It uses a liquid coolant (usually a combination of antifreeze and water) that flows through channels in the engine head and block. In this way the liquid absorbs heat and transfers it to the radiator where the heat is released to the air.

- **Radiator:** The radiator is made of aluminum tubes and fins and transfers heat from the hot coolant to the outside air. (The radiator may have a mechanical or electric fan to increase the airflow over the radiator for cooling purposes.)
- **Water Pump:** Circulates coolant through the engine and radiator. Usually located at the front of the engine and driven by a belt.
- **Thermostat:** Controls coolant flow based on temperature, allowing the engine to warm up quickly and quickly reach optimum operating temperature. At warm-up, the thermostat remains closed, allowing the coolant to bypass the radiator and open as the coolant temperature increases.
- **Radiator Cap:** Maintains system pressure, raising the coolant's boiling point. It releases excess pressure to a reserve tank to prevent damage.
- **Coolant (Antifreeze):** Water and ethylene glycol are usually mixed together, with additives to prevent freezing, boiling, and corrosion. Common types are IAT, OAT, and HOAT .

### **I.4.2.2 Air Cooling System (Alternative):**

Found in some motorcycles, small engines, and older vehicles. Air is blown over engine fins to remove heat, and the efficiency of the cooling system will depend on how well the fin is designed and how much air flow is available .

### **I.4.3 Power Supply System:**

An internal combustion engine's (ICE) power supply system supplies the electrical energy required for engine starting, auxiliary system functioning, and control.

- **Battery:** The battery is the main source of electrical power when the engine is not running and when the engine is starting. The battery provides electrical power to the starter motor, ignition system, fuel injection system and engine control unit (ECU).
- **Power Supply Lines and Harnesses:** There are dedicated power supply lines that connect the battery to the electrical systems of the engine. These lines are often kept separate from the signal lines to keep the power steady and to lower interference.
- **Main Switch and Stop Switch:**
  - **The main switch** controls the overall connection of the battery to the engine's electrical system. It is typically in the "on" state during engine operation.
  - **The stop switch** is used to interrupt power and safely shut down the engine. It is normally "off" during operation and activated when stopping the engine .
- **Engine Control Unit (ECU):** The ECU manages engine functions such as ignition timing and fuel injection. It receives power from the battery through the relay and power supply lines. The ECU includes:
  - An arithmetic processing section (CPU) for engine control operations.
  - A power supply circuit to convert battery voltage to appropriate levels for electronic components.
  - Circuits to monitor and respond to main and stop switch signals, ensuring reliable engine operation .

**In the following will take a closer look at the distribution system, the object of our work.**

## **I.5 The distribution system :**

The timing system in an engine is in charge of controlling the moment that intake and exhaust valves move. It takes care of the opening and closing of the valves and makes sure they are

timed with the movement of the piston. The timing system is broken down into the following components.

## **I.5.1 Distribution system component :**

### **I.5.1.1 Camshaft :**

A camshaft is essentially a simple component – a simple stoked length of rod or shaft that consist of shaped lobes that are referred to as cam lobes. When the shaft rotates, the shape of the cam allows it to act upon a valve, or switch, to a degree with how pronounced the shape is, and the action rate by how quickly it is rotating.

In modern internal combustion engines, they are usually (but not always) located directly above the cylinder banks that they control the valves. The calibrations exactly control the amount air-fuel mixture that enters the chamber and how effectively the spent exhaust gases from the previous ignition, can exit in order to make room for the next charge.

This means that not only are they essential in the operation of an engine but because the opening and closing of the valves must be literally and completely synchronous with the motion of the pistons, they have a huge impact on performance, as well.

The camshafts are synchronized to the turning of the crankshaft by means of a timing belt or timing chain - and the crankshaft is directly turning the pistons inside the cylinder [5].



**Figure 8** Camshaft [6].

### **I.5.1.2 Valves:**

Intake and exhaust valves are valves that regulate the flow of fresh air/fuel into the combustion chamber and the flow of exhaust gases out of the combustion chamber. The valves are acted upon by the cams mounted on the camshaft to open and close [7].



**Figure 9** Engine valves [8].

### **I.5.1.3 Valve springs:**

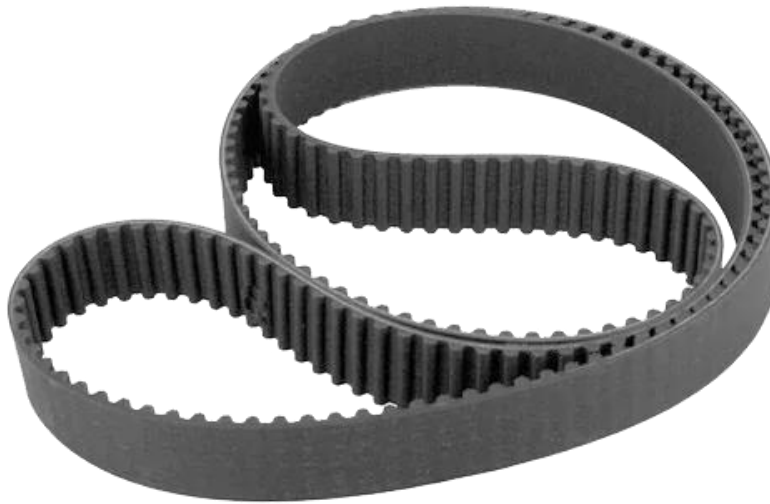
Valves are located in the engine and held in a closed position by valve springs. The valve springs in question hold the necessary pressure when the valve is not opening to assure that the valve closes tightly [6].

### **I.5.1.4 Rocker arm pushrods/rods:**

In some engines, the camshaft cams are directly on the valves via rocker rods or tappets, which then perform the same function, transferring the movement of the camshaft to the valves [7].

### **I.5.1.5 The transmission belt:**

Belts are power transmission elements used to transmit motion and torque between two parallel rotating shafts. They are widely used in industrial machinery and equipment, cars and motorbikes, and household appliances [7].



**Figure 10** Toothed timing belt [9] .

-In most engines, the camshaft is driven by the crankshaft using a chain or toothed belt, which is kept taut by a belt tensioner [7].

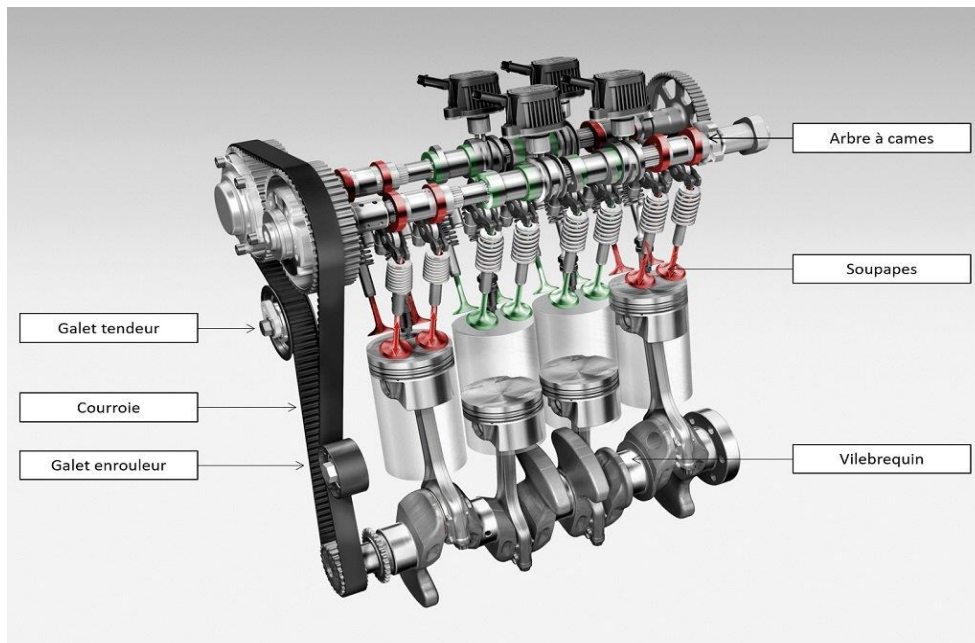
Precise alignment of the camshaft in relation to the crankshaft is important to ensure that the cams operate the valves at the right time. The valves must open and close at precise times to allow the fuel-air mixture to enter the cylinder and to exhaust the exhaust gases. If the camshaft is not aligned correctly, the valves may open and close too early or too late, resulting in power loss and engine damage.

The gear ratio in an internal combustion engine generally refers to the relationship between the speed of rotation of the crankshaft and the speed of rotation of the camshaft. The gear ratio is determined by the camshaft configuration and can vary according to the engine specification. The transmission ratio can be fixed or variable, depending on the timing system used.

Most internal combustion engines typically rotate clockwise (viewed from the front of the engine). However, there are a few instances where this does not apply, such as some rotary engines or specialized applications.

Timing is critical to engine operation, as timing relates to when the valves open and close in synchronization with the position of the piston. Incorrect timing of the engine may not only cause performance issues and a loss of power but also causes valve wear and/or potential internal damage. Synchronization (timing) is typically accomplished by aligning the marks on the camshaft and crankshaft, based on manufacturer specifications.

Rotary motion is accomplished by a drive chain or belt toothed to sprockets attached to the camshaft and crankshaft [7].



**Figure 11** Technical image of a 4-cylinder engine showing camshaft, crankshaft, pistons, valves, and timing belt components [10].

## **I.5.2 Description of K7M800 (engine):**

The K7M800 is indeed a 1.6-liter (1598 cc) inline-4 petrol engine with 8 valves (2 valves per cylinder), a naturally aspirated engine with a multi-point fuel injection system. It has a cast iron cylinder block and an aluminum cylinder head. The engine is driven by a toothed timing belt to the overhead camshaft(s) with an EGR (Exhaust Gas Recirculation) of emission control. The compression ratio is around 9.5:1. It is compliant with Euro 3 emissions and it is designed to run on regular petrol (92 octane) fuel [12][13][14].



**Figure 12** Renault K4M 1.6L engine [14].

### **I.5.2.1 Historical of K7M800:**

- The K7M engine series, with K7M800 as part of it, launched in 1995. Initial production of these engines was in Spain, specifically in Valladolid plant, and the engines first made their debut in vehicles like the first-generation Renault Megane and Scenic.
- Now, specifically the K7M800 was a brand new development in this engine series that offered an inexpensive and dependable performance level at ~85hp and ~135 Nm of torque.

- In 2004, once the first generation Megane and Scenic has ceased production, the production of K7M800 was transferred to Romania, where it became the main engine used for Renault's budget brand, Dacia, which included Logan, Sandero, Stepway, and Lodgy models.
- The engine was also exported to Russia for use in vehicles including the Lada Largus station wagon and van from 2012 to 2015.
- The K7M800 did have a reliable reputation for being simple and tough through its life cycle, with a projected life expectancy of ~400,000 km with proper maintenance.
- Although, it is true that the engine had its share of issues, particularly the need to change the ignition coils as well as timing belts every 300,000 km, the engine continued to be regularly used in cheap compact cars well into the 2000s - early 2010s [12][15][16].

### **I.5.2.2 Performance:**

The K7M800 produces about 62 kW (83 hp) at 5250 rpm, and has a maximum of about 128–135 Nm of torque at around 3000 rpm. Fuel consumption is typically around 7.2 liters per 100 km in combined conditions, and 0-100 km/h takes around 11.5 seconds in typical vehicles like the Dacia Logan and Sandero [12][14][17].

### **I.5.2.3 Functional and Technical Parameters:**

**Table 1** Functional and Technical Parameters of K7M800

cylinder capacity	1598 $cm^3$
Configuration	Inline 4-cylinder
Valves	8 (2 per cylinder)

Chapter I : Generalities general information about the internal combustion engine

---

Bore x Stroke	79.5 mm x 80.5 mm
Aspiration	Naturally aspirated
Fuel system	Multi-point fuel injection
Cylinder block	Cast iron
Cylinder head	Aluminum
Timing	Belt-driven overhead camshaft
Compression ratio	~9.5
Power output	83–86 hp (varies slightly by variant)
Torque	128–135 Nm
Oil capacity	~3.6 liters, recommended oils 5W-30 or 5W-40
Emission standard	Euro 3
Engine lifespan	Approximately 400,000 km under normal maintenance

#### **I.5.2.4 Commonly used chassis:**

The K7M800 engine has mostly been found in budget compact cars such as the Dacia Logan and Dacia Sandero since roughly 2011, and in some Lada vehicles, as it is regarded for reliability, simplicity, and maintenance [14][17].



**Figure 13** vehicle Dacia Sandero I Stepway [18].

#### **I.5.3 Conclusion:**

With a basic grasp of internal combustion engines (ICE), the classical distribution system, and the specifics of the K7M800 engine, we're ready to explore further down to valve control arrangements. The demands in terms of performance, and especially power, efficiency, and emissions all influence the design of the valve timing system, and in turn this shows a need for new valve timing systems designs. We now move on to consider new camshaft designs and advances in technologies such as variable valve timing, which is the contemporary version of fixed-timing designs. The prospect of the next chapter examines the mechanical principles, advantages, and application of new technologies to continually produce optimized applications.

The main object of our study is the improvement of the power of the chosen engine. To this end, we present solutions and transformations on the work distribution system, which will be developed in the next chapter.

# **Chapter II :**

## **Design and Development of Cam Profiles**

### **II.1 Introduction**

The efficiency and performance of an internal combustion engine relies heavily upon its ability to control the timing and lift profiles of its valves effectively. We see the cam that is responsible for this function at the core of it all, as its geometry dictates how much the intake and exhaust valves open and close as the engine cycles. If the cam profile is optimized effectively, the air-fuel mixture can be taken in properly, and the exhaust gases can exit the building engine efficiently; both of these characteristics will affect torque, power, and fuel consumption.

Only a few cam designs that exist today offer variations and the timing profiles of traditional functional cams offer limited performance as they do not enable the adjustment of timing characteristics on multiple engine conditions. In order to offer a solution to this limitation, Variable Valve Timing (VVT) systems were developed. VVT systems allow the dynamically scheduled valving events to account for engine speed and load; they are being utilized for VVT gains in efficiency, emissions, and response.

This chapter will first focus on the basics of cam design and explain how cam profiles influence valve movement, before laying the groundwork by reviewing major VVT system types, VVT system functions, and how they have been incorporated into most modern engines. From this point it will open up the analysis of the K7M800 engine.

### **II.2 Variable Valve Timing Systems:**

Variable Valve Timing (VVT) is a concept in internal combustion engines that changes the timing of the events of valve lift over time - the opening and closing of the intake and exhaust

valves, and, in some systems, the duration and lift of the valves. The goal of VVT is to improve performance, fuel economy and emissions over a range of engine speeds and loads.

-VVT changes the timing of the valves by positioning the camshaft, which means changing the orientation of the camshaft with respect to the crankshaft. This can be accomplished using different types of cam phasers that can be opened using hydraulic or electronic control. There are also automotive systems that vary lift or duration of the valve at specific points in the cycle [20][21].

### **II.2.1 Objective:**

- Our primary aim is to enhance engine effectiveness by adjusting valve timing for peak power at high RPMs and maximum torque at or near low RPMs.
- To support fuel economy improvements by developing the optimal air-fuel ratio and combustion under variable operating conditions.
- To minimize emissions by directing valve overlap and exhaust gas recirculation and adhere to stricter environmental regulations .

### **II.2.2 Mechanism of VVT:**

The engine control unit (ECU) monitors real-time engine load, speed, and temperature.

To control the VVT system to advance or retard camshaft timing hence alter the opening and closing of the valves based on the defined parameters.

This is accomplished in continuous mode or a switch/plunge-style based on the engine's operating conditions as outlined in very basis pre-defined engine profiles.

Some systems can also change the lift and duration when the valves are open improving airflow through the engine at the same time and increasing combustion efficiency [20][21].

### II.2.3 The different types of variable distribution:

Variable valve timing (VVT) is a technology that allows adjustment of variable timing (opening and closing moments) and/or lift (opening amplitude) of internal combustion engine intake and exhaust valves for performance improvement, fuel consumption, and/or pollutant reduction by optimizing the combustion cycle according to specific operating conditions.

#### II.2.3.1 Variable Valve Timing (VVT):

Variable valve timing adjusts when the valves open and close depending on engine speed and load. The valve, camshaft and crankshaft synchronization is adjusted sequentially.



**Figure 14** VVT system [25].

- **Simple Phasers:** These rotate the camshaft in relation to the timing pulley which will alter the valve timing. The system is often hydraulic and is controlled by either a solenoid valve or oil pressure.

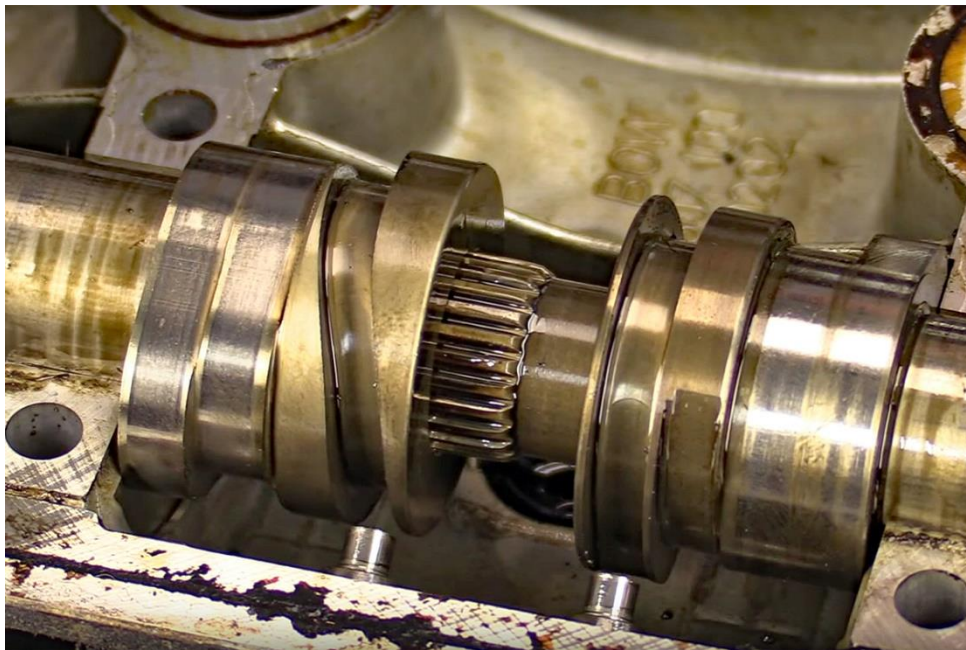
- **Commercial Examples:**

- **VVT-i (Toyota):** Utilizes a solenoid valve to control oil pressure and shift the intake camshaft.
- **VANOS (BMW):** Hydraulic phaser system for variable timing.

Variable valve timing enables power increase at high RPM by opening valves earlier and longer or torque improvement at low RPM by either retarding or advancing an opening [22][23].

### II.2.3.2 Variable Valve Lift:

Variable valve lift modifies the opening amplitude of the valves, thus the amount of air admitted into the cylinder.



**Figure 15** VVL system [25].

- **Multi-Cam or Offset Cam Systems:** The axial position of the cams is modified to select a cam with a different lift.

- **Commercially Available Systems:**

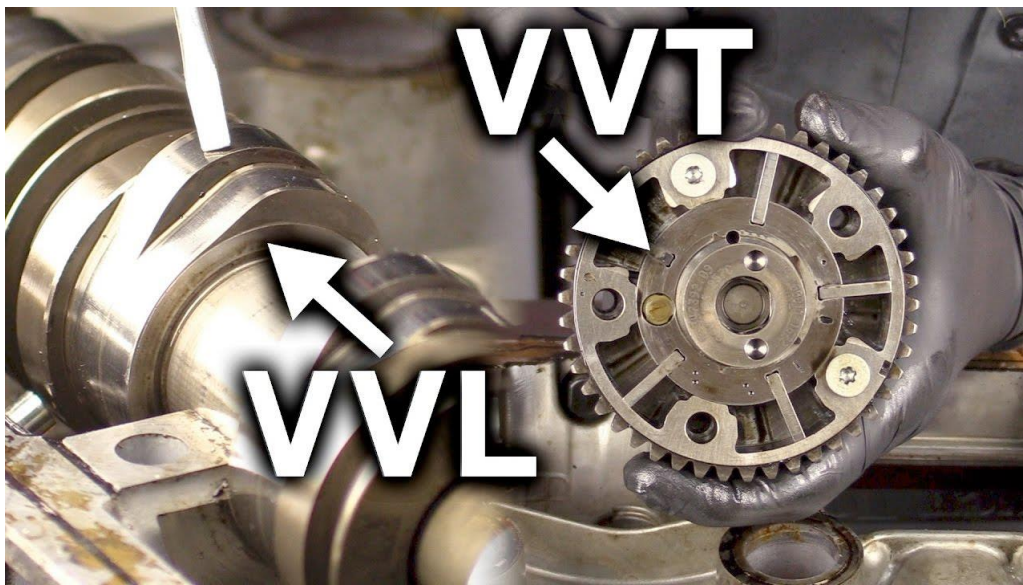
- **VALVELIFT (Audi):** Alters the cam's axial position to provide new lift.
- **VTEC (Honda):** Utilizes multiple cam profiles and an extra valve to switch between a low lift and a high lift depending on engine speed.
- **Valvetronic (BMW):** Instead of a throttle valve, it has an electric system that changes the lift of the intake valves, allowing for a better air metering precision.

Variable valve lift allows greater control of cylinder filling, reducing fueling consumption and emission, while also enhancing performance [23][24].

### II.2.3.3 Combined Variable Timing + Lift Systems:

Some current engines are already able to combine both technologies for the best benefit:

- **Double VANOS + Valvetronic (BMW)**
- **VVTL-i (Toyota):** Use variable timing and variable lift.
- **VTEC (Honda):** Variable timing and variable lift determined by cam profiles [23].



**Figure 16** VVT vs VVL systems [25].

### II.2.3.4 Other Technologies and Strategies:

- **Early Inlet Valve Closing (EIVC) & Late Inlet Valve Closing (LIVC):** The early or late closing of intake valves to increase filling and decrease fuel consumption.
- **Variable Timing on Intake and Exhaust:** Variable timing can refer to either the intake valves, the exhaust valves, or some combination depending on the engine design.

### II.2.4 Choice of distribution type:

In our work, we are only interested in variable valve lift, or changing the distance that the valve opens. Variable valve lift is different than changing only the timing because variable valve lift allows the intake and exhaust valves to have different lift heights which gives more precise control of the amount of airflow going into the engine and results in greater efficiencies and thirty percent responsiveness under different driving conditions.

#### II.2.4.1 Variable valve Lift systems:

- **Cam-Switching Systems:**
  - ✓ **Design:** Incorporates multiple cam lobes (e.g. low-lift, high lift) onto the camshaft. At the specified RPM, hydraulic or electronic actuators hold appropriately the cam profile to valve-train.
  - ✓ **Example:**
    - Honda VTEC:** Uses a pin pressure that is actuated/held by oil pressure to put a pin through the rocker arms of the different cam profile.
    - Toyota VVTL-i:** Uses variable timing (VVT-i) in combination with switching cam. At 6,000 RPM, hydraulic pressure enabled a pin to lock the high-lift cam, resulting in added lift and duration [26][27].
- **Oscillating Cam Systems:**

✓ **Design:** Uses an eccentric cam or intermediate lever instead of a traditional cam, allowing for continuous variation of lift.

✓ **Example:**

**BMW Valvetronic:** employs an electric motor to rotate an intermediate lever to change effective cam profile height. The throttle valve is eliminated resulting in reduced pumping loss.

**Nissan VVEL:** can vary the pivot points of the levers using a DC motor, providing infinite control of lift [28].

- **Eccentric Shaft Systems:**

✓ **Design:** Rotates an eccentric shaft to alter the fulcrum point of the rocker arm, changing lift amplitude.

✓ **Example:**

**Audi VALVELIFT:** Shifts the camshaft laterally to engage different lobe segments, altering lift.

#### **II.2.4.2 Enhancing Engine Output and Economy through Variable Valve Lift:**

Variable valve lift (VVL) can enhance engine performance and efficiency by adjusting the lift of the intake and/or exhaust valves based on the engine speed, engine load, and engine operating conditions. The adjustable lift allows maximum oxygen intake into the engine while maximizing exhaust gases, optimally tuning the engine's intake and exhaust systems to demands placed on it. There are several advantages to VVL:

- **Improved Airflow Control:** The engine is able to maximize airflow when it needs it (high RPM) and reduce airflow (valve lift) when it doesn't (low RPM) in order to improve fuel economy and pumping losses. This type of engineering allows the air intake to more closely match combustion needs, thereby increasing volumetric efficiency and combustion quality [26][28][29][30].

- **Enhanced Fuel Economy:** Less lift indication at part-load or low-speed operations leads to less intake restriction and pumping loss which will allow the engine to use less fuel. Research shows that whereas VVL can result in about a 10–14% improvement in brake specific fuel consumption at part load, this feature can contribute to a total fuel savings ranging from 1–6% [28][29][31].
- **Power and torque also increase:** Increased valve lift means more air-fuel mixture enters the cylinder at higher engine speeds, resulting in increased power and torque. Overall, the responsiveness and performance of the engine across a wide RPM range is noticeably improved [26][28][29][30].
- **Reduced emissions:** Optimizing valve lift promotes more complete and efficient combustion reducing hydrocarbon (HC) emissions and other pollutants. More complete combustion stability at lower loads also reduces emissions of unburned fuel [26][28][29].
- **Throttling Loss Reduction:** Systems such as Nissan's VVEL eliminate or lessen the need for a traditional throttle valve by controlling intake air through valve lift directly; it reduces pumping losses and increases throttle response [28].
- **Refined Engine Smoothness and Flexibility:** Continuous or discretely variable valve lift systems give up front-end abruptness in engine behavior, which results in smoother power delivery and better drivability than fixed or discretely variable valve lift systems [26].

### II.2.5 Description of VVL elements:

Variable Valve Lift (VVL) systems provide either continuous or discrete adjustment of the valve lift in internal combustion engines to optimize performance for a given engine condition as the valve can open to different amounts of lift at specific times. Variable lift in engine technology achieved by a number of mechanical designs and components, which can use complex linkages, camshaft or cam configuration mechanisms. The description that follows was made with the help of previous research and industrial implementations.

- **Camshaft:**

The camshaft is still the main driver of valve motion. The camshaft is multi-lobed, and in VVL systems, it may be coupled to a more complex mechanism, altering valve lift dynamically.



**Figure 17** Camshaft modeled in SolidWorks [40].

- **Cam:**

In Variable Valve Lift (VVL) systems, the cam operates to control the rate of lift, timing, and duration of the engine valves. By utilizing multiple cam profiles or adjustable cams, VVL systems are capable of modifying the relationship between the lift the valve opens based on engine load and speed, improving performance and efficiency.



**Figure 18** Cam modeled in SolidWorks [40].

- **Rocker Arm(s):**

The rocker arm translates the motion of the camshaft into motion of the valve. The rocker arm typically has a variable fulcrum in variable valve lift (VVL) systems, or it functions as part of a multi-link device that can vary lift. Various other designs use a roller rocker finger or intermediate rocker, which helps reduce friction and has improved kinematics.



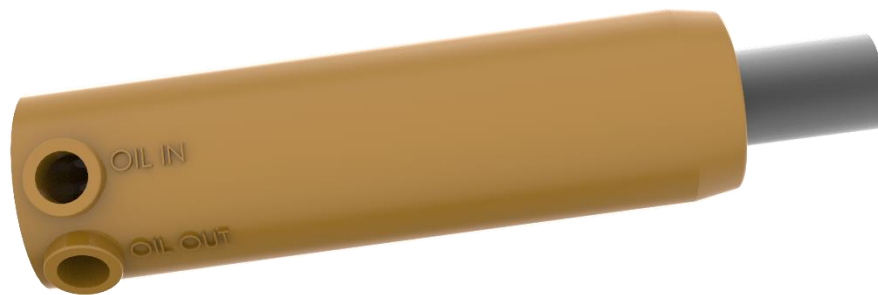
**Figure 19** Rocker modeled in SolidWorks [40].

- **Control Shaft / Eccentric Shaft:**

An eccentric or control shaft is employed when variation in the linkages of the valve train is needed. The fairly eccentric shaft is possessing one or more cams whose effective range of motion can vary continuously or discretely when turned. This turning motion is typically produced by an electric motor or hydraulic actuator.

- **Actuators (Electric or Hydraulic):**

Electric motors (e.g., DC motors with ball screws), or hydraulic systems control the position of the eccentric shaft or control arms which allow for valve lift that can be accurately and quickly adjusted.



**Figure 20** actuator modeled in SolidWorks [40].

- **Sensors and Control Unit (ECU):**

Position sensors monitor the positioning of the control shaft or actuator, delivering the positional output to the engine control unit (ECU) where the valve lift is controlled relative to engine speed, load or other factors [31].

To understand how the Variable Valve Lift system operates to provide its benefits, we must consider the mechanical principles behind the operation of the valves. The camshaft, in particular, is important because it is the shape of the cam shaft that dictates the motion of the valves. This will help to provide us an understanding of the theory of cams and how it operates



**Figure 21** camshaft position sensor modeled in SolidWorks [40].

to lend itself to variable valve lift capabilities of altering valve timing and lift for improved power delivery and efficiency.

## **II.2.6 Cam theory and role:**

### **II.2.6.1 Cam role :**

A cam is a mechanical device that translates rotary motion into linear (or reciprocating) motion. A cam has an oscillating piece that rotates and pushes against a follower, moving the follower in a carefully controlled manner based on the profile of the cam. Essentially, the cam is modifying how the follower(s) move based on the profile of the cam. The cam produces repeatable motion in a follow with precise control over timing, displacement, velocity, and acceleration. Cams have a variety of applications in an engine to open and close valves, and they can also be used in machines that require multiple movements in a complex, repeatable motion. The movement of the follower, which consists of rise, dwell, and fall, is based on the cam profile, so a cam is a great means of precisely controlling mechanical motion [32][33].

### **II.2.6.2 Theory:**

A cam is a mechanical device that utilizes rotary continuous motion to control a portion (the follower) by converting that motion into a prescribed (often complex) reciprocating or oscillating motion. The cam is comprised of a shaped surface or profile that rolls or slides against the follower and displaces the follower according to a precise program of motion.

- **Motion Conversion:** The cam takes a continuous rotary input and transforms it into controlled, usually non-linear, linear or rotational output motion of the follower. This allows for complex motions to be created through a single rotation.
- **Cam Profile:** The cam surface (or profile) encodes the motion law which must be imparted to the follower. The cam was constructed to impart a certain displacement, velocity, and acceleration during the angle of rotation of the cam.

- **Follower:** The component engaging the cam, which can either translate (move in a straight line) or oscillate (rotate about an axis). The follower's motion follows the cam contour.
- **Contact and Force Transmission:** The cam and follower have continuous contact, often ensured by a spring on the follower to prevent them from losing contact, causing vibration and loss of precise control of motion. The contact can be either direct (the follower tip against the cam surface) or indirect (the follower has a roller to reduce friction) [34].

### **Motion Law and Design Constraints:**

- **Law of Motion:** The required motion of the follower is given in terms of its displacement  $x$  as a function of time  $t$  or cam angle  $\theta$ . The cam profile is then developed to generate this motion.
- **Design Objectives:**
  - ❖ Restricting maximum speed can help reduce energy use and wear.
  - ❖ Restricting acceleration can help minimize dynamic forces and mechanical stress.
  - ❖ Reducing "jerk" (the change of acceleration) can help keep shocks, vibrations, and noise to a minimum.
- **Continuity:** The cam profile must be continuous and smooth, without sudden jumps ("steps"), which would cause follower "teleportation" and mechanical damage [34].

### **Application :**

- **Internal Combustion Engines:** Cam lobe on a camshaft and engage or disengage intake and exhaust valves with a specific timing and lift.

- **Automated Machinery:** Cams are used to control a tool's movement, indexing and sequencing when manufacturing parts.
- **Other Mechanical Systems:** Cams are used at any time a motion pattern becomes complex and needs to repeat.

Cams are widely applicable across many fields. Cams are preferable to convert rotary motion into linear or oscillating motion because they provide precise control with little backlash. In automotive engineering, you will find a cam in an internal combustion engine because it controls the operation of the valves (i.e., lift and timing when the valve opens or closes). If the cam is poorly designed, optimal engine performance, and fuel economy may not be assured. Cams appear in machinery for manufacturing to control cutting, shaping, or forming a process to ensure that something is created accurately and consistently. A robot uses cam and follower designs to perform a task such as pick-and-place operations. You will find cams in printing presses and textile machines and in medical devices such as ventilators, where they are essential for sequences of motion that involve complex manipulation and precise control of speed or distance moved. The ability of a cam to produce complex motion profiles while providing precise control makes it a highly favoured mechanism in mechanical applications [32][33].

### **II.2.7 Application of Cam Theory using MATLAB:**

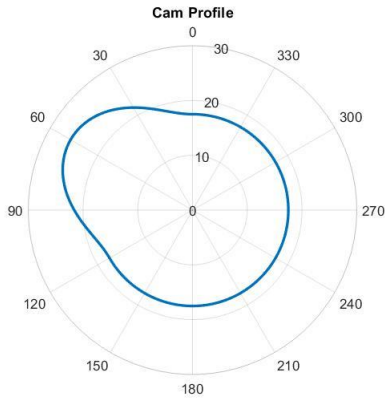
To validate the theoretical concepts of cam design presented earlier, we carried out a practical modeling of a cam profile using MATLAB. The objective of this step was to generate the geometric profile of the cam and to evaluate the corresponding valve lift as a function of the camshaft angle.

Using the equations of cam kinematics and the parameters defined for our design, MATLAB allowed us to plot the polar representation of the cam profile (Figure 23) as well as the lift curve of the valve as a function of camshaft rotation (Figure 22).

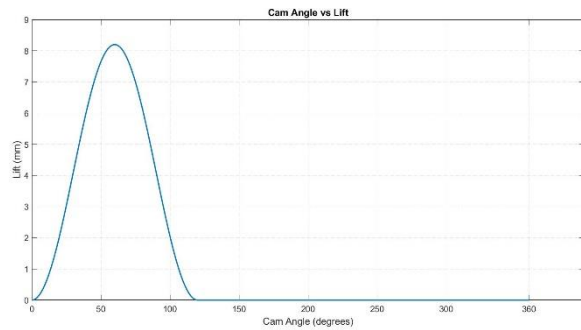
The polar cam profile clearly shows the geometry obtained after applying the cam motion law, while the lift curve highlights the maximum lift of approximately 8.2 mm reached around 50° of cam rotation, followed by the closing phase of the valve. These results confirm the feasibility

of our cam design and provide a basis for integrating the profile into the global distribution system.

- **Intake and exhaust cam:**

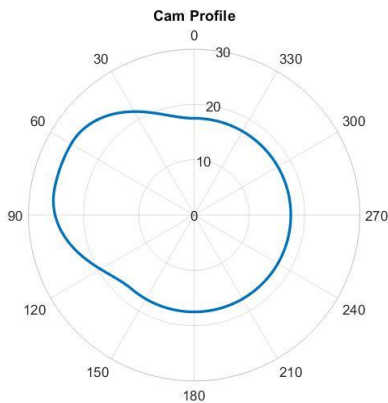


**Figure 23** Cam profile design obtained with MATLAB

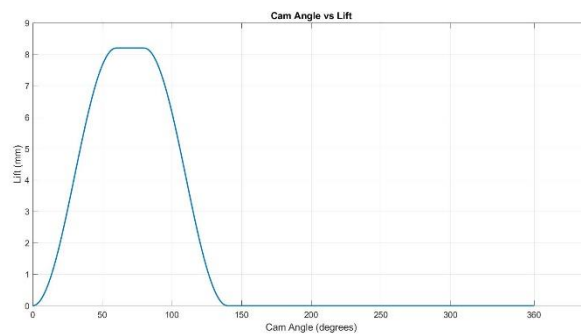


**Figure 22** intake and exhaust cam graph

- **VVT cam :**



**Figure 24** VVT cam design obtained with MATLAB



**Figure 25** VVT cam graph

### **II.3 Conclusion :**

By reviewing the various types of variable valve timing devices, the conceptual and practical investigation of cam systems, we have provided a solid grasp of the mechanical principles and components applicable to achieving the optimal condition of engine cycles. With the foundation of this conceptual understanding, we will now move onto the next phase of the work - practical dimensioning of variable valve timing systems. Chapter 3 will now provide the dimensioning of components such as valves, springs, belts, and the camshaft and will facilitate the calculation and determination of cam profiles from the trajectories of valve lifts.

## **Chapter III :**

### **Belt and Cam phaser Dimensioning**

Following the examination of the different types of variable valve timing systems and the study on the theoretical action of cams in mechanical control, we move on to the implementation stage. In this chapter, the activities are dimensioning and selecting the various components that form the variable valve timing system. From the valves and springs to the camshaft and cam phaser, all the components must be calculated and sized to guarantee dependable and efficient operation of the engine under all service conditions.

#### **III.1 Advantages of the variable system compared to the conventional system and the energy gain of a variable valve timing (VVT) engine compared to a conventional valve timing engine:**

##### **III.1.1 The advantages:**

###### **III.1.1.1 Optimizing cylinder filling:**

By using a variable valve timing system, cylinder filling can be optimized by altering the timing of the intake valve opening and closing moments with respect to engine speed. With engine speed at low rpm, an earlier closure of the intake valve prevents the fresh charge from flowing back, resulting in improved torque and drivability. With the engine speed at high rpm, a later closing of the intake valve can be used to take advantage of the inertia of the intake air, allowing the cylinder to fill with a greater mass of air, and improved volumetric efficiency. This dynamic adjustment means improved torque at low speed, and greater power output at high speed relative to a fixed-timing valve train [38].

#### **III.1.1.2 Increasing engine torque at low revs:**

The VVT system enhances engine torque at low revs by advancing the intake valve timing to improve cylinder filling and combustion. Using optimum valve overlap to minimising charge losses the engine produces stronger torque at low speed, which improves power, drivability and overall suppressiveness compared to a conventional system[38].

#### **III.1.1.3 Increase in maximum power:**

The increase in maximum power comes from the ability to delay the closing of the intake valves when the engine is at high RPM. Typically, the standard timing system with mechanical operation would close the valves while the piston is moving up in the compression stroke of the cycle, not allowing air to fill the cylinder. When the timing is able to be varied, the inertia of the incoming air can fill the cylinder after the piston passes the top of the cycle, increasing the volumetric efficiency of the engine thereby allowing the engine to consider more air-fuel mixture to burn, resulting in more power than a timing-based system [39].

#### **III.1.1.4 Reduction in fuel consumption:**

The VVT scheme will reduce fuel usage by enabling the system to adjust the timing of the valves so that it can reduce pumping losses and increase combustion performance. At low and medium loads, the optimized overlap effectively reduces wasted energy to draw in air into the cylinders. At high-load incidents, the ability for increased filling allows for the engine management system to operate more efficiently. Thus, the system allows the engine to use less fuel throughout a much larger range of operating conditions and records assume a fixed-timing design.

#### **III.1.1.5 Reduction in pollutant emissions:**

The VVT system can aid in the reduction of pollutant emissions by optimizing the valve overlap situations and gas exchange to varying engine operating conditions. At low loads, less overlap helps eliminate unburned hydrocarbons (HC) by reducing fresh charge losses. At higher loads, proper overlap allows for controlled internal exhaust gas recirculation, reducing combustion temperatures, which can often reduce nitrogen oxides (NOx). Thus, the VVT allows for

flexibility to the engine to make it cleaner and emissions compliant compared to fixed timing systems [39].

**III.1.1.6 Engine flexibility and versatility:**

The VVT system significantly broadens engine capability by fine-tuning the valve timing for specific driving scenarios. Whereas fixed-timing systems must make trade-offs between low-speed torque and high-speed power, VVT systems continually reflect the demands of the engine, delivering low-speed torque and high-speed performance. This leads to smooth operation, better responsiveness in urban conditions, and excellent performance even at high speeds. The gulf has been bridged, expanding the operating range of the engine.

After presenting the main benefits of the Variable Valve Timing (VVT) system compared to the conventional fixed-timing system, we must now quantify these improvements from an energetic standpoint. Indeed, evaluation of gain in power and efficiency capabilities is necessary in terms of quantifying the real contribution of VVT. In the following section, we will calculate the supplementary energy acquired due to the optimized timing of the valves.

**III.1.2 The energy gain of a variable valve timing (VVT) engine compared to a conventional valve timing engine [41]:**

**III.1.2.1 At equal power (same load and speed):**

We start with brake performance:

$$\eta_b = \frac{P_b}{\dot{m}_f \times \text{PCI}} \dots\dots\dots (1).$$

Where  $P_b$ = braking power,  $\dot{m}_f$ = fuel mass flow rate, PCI= lower heating value. The efficiency gain (and therefore “energy gain”) of VVT is:

$$G_\eta (\%) = \frac{\eta_{b,VVT} - \eta_{b,clas}}{\eta_{b,clas}} \times 100 \dots\dots\dots(2).$$

By replacing  $P_b$  by the above expression with identical power (same  $P_b$ , same fuel, therefore same PCI), we obtain a formula that can be used directly with the fuel flow rate:

$$G_{\eta}(\%) = \left( \frac{\dot{m}_{f,clas}}{\dot{m}_{f,VVT}} - 1 \right) \times 100 \dots\dots\dots(3).$$

Equivalent to specific brake consumption (BSFC,  $c_s = \dot{m}_f / P_b$ )

$$G_{\eta}(\%) = \left( \frac{c_{s,clas}}{c_{s,VVT}} - 1 \right) \times 100 \dots\dots\dots(4).$$

### III.1.2.2 At equal fuel flow (same $\dot{m}_f$ )

If you impose the same fuel flow rate, the power gain is:

$$G_P(\%) = \frac{P_{b,VVT} - P_{b,clas}}{P_{b,clas}} \times 100 \dots\dots\dots(5).$$

### III.1.2.3 Variant by mean effective pressure (BMEP):

If you are working with BMEP (or IMEP):

$$P_b = \text{BMEP} \times V_d \times \frac{n}{2} (4T) \dots\dots\dots(6).$$

at speed  $n$  and displacement  $V_d$ , identical, then:

$$G_P(\%) = \frac{\text{BMEP}_{VVT} - \text{BMEP}_{clas}}{\text{BMEP}_{clas}} \times 100 \dots\dots\dots(7).$$

in our case we'll take:

conventional engine:  $\dot{m}_{f,clas} = 10 \text{ g/s}$

VVT engine:  $\dot{m}_{f,VVT} = 8.8 \text{ g/s}$

$$G_{\eta} = \left( \frac{10}{8.8} - 1 \right) \times 100 \approx 13.6$$

13.6% improvement in efficiency (or fuel economy) thanks to VVT.

## III.2 Dimensioning of variable distribution components:

### III.2.1 Timing belt [6]:

This stage of the calculations concerns the upper part of the transmission system we've designed, which in turn transfers motion (between the intermediate pinion of this system and the camshaft) with a synchronous toothed belt. All the data for the transmission we're going to design are for the internal combustion engine of a Renault Sandero 1.6 MPI ,90hp [6].

We already discuss our engine K7M800 in chapter1 but here's the technical specifications that we need:

**Engine Power (P):** 67 kW @ 5,250 rpm

**Cam pulley speed ( $n_1$ ) :** 2750 rpm

**Center distance (a) :**  $\approx$  600 mm

**Small pulley diameter ( $D_1$ ) :**  $\approx$  60 mm

**Large pulley diameter ( $D_2$ ) :**  $\approx$  120 mm

#### Calculs:

To calculate a synchronous belt in an internal combustion engine timing system, several parameters are taken into account, including the distance between pulleys, the number of belt teeth and the belt pitch. It's important to note that calculations may vary depending on the specific type of timing belt used and the characteristics of the engine's timing system. Precise parameter values should be obtained from the belt manufacturer or engine specification.

#### III.2.1.1 Determination of service factor k:

It is important to select an appropriate service factor to ensure optimum belt life.

A service factor value that is too low can lead to belt overload, while one that is too high can lead to belt under sizing.

According to [6], in our case the factor  $k = 1.15$ .

### III.2.1.2 Effective power :

In the context of an internal combustion engine, effective power refers to the actual mechanical power produced by the engine, which is available to perform work, such as turning a shaft or propelling a vehicle. It is important to note that effective power is generally lower than the total power generated by fuel combustion in the engine.

$$P_e = P_m \times K = 67 \times 1.15 = 77.05 \text{ KW}$$

$P_e$  : Effective power (KW).

$P_m$  : engine power (KW).

$K$  : Service factor.

We have estimated that the power required to operate the distribution in an MCI motor will be of the order of 20% of the power produced by the motor [6].

$$P_{camshaft} = \frac{P_e \times 20}{100} = \frac{77.05 \times 20}{100} = 15.41 \text{ KW}$$

### III.2.1.3 Speed ratio:

$$R_1 = \frac{d_1}{d_2} = \frac{60}{120} = 0,5$$

$R_1$ : Speed ratio between intermediate pulley and camshaft pinion  $d_1, d_2$ .

$d_1$ : Diameter of intermediate pulley.

$d_2$ : Diameter of camshaft pinion.

### III.2.1.4 The linear speed of the toothed belt:

The linear speed of the toothed belt in an internal combustion engine timing system is the speed at which the belt moves along its path. This speed depends on the rotational speed of the drive pulley and the pulley diameter.

$$V = \frac{\pi \times d_i \times N_1}{60 \times 1000} = \frac{3,14 \times 60 \times 2750}{60 \times 1000} = 8.635\text{m/s}$$

### III.2.1.5 Choice of belt type :

The choice of belt type for an internal combustion engine timing system depends on a number of factors, such as engine power, speed, space constraints, operating environment, timing requirements, required durability, and so on.

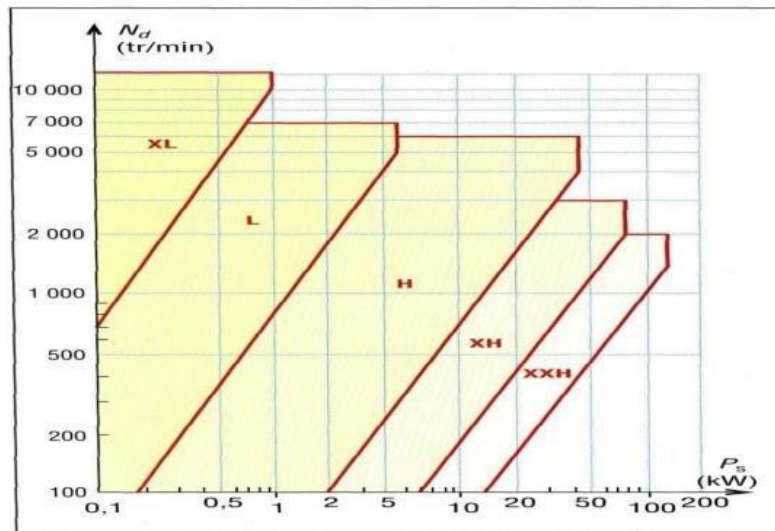


Figure 26 power rating range .

Using Figure26, hang the vertical line from  $P_{camshaft} = 15.41KW$  and the horizontal line from  $N_d(N_1) = 2750rpm$  they will intersect in the range of the belt (H).

The H-type synchronous belt is a standardized toothed belt designed to transmit rotary motion without slippage between two shafts. It has a pitch of 12.7 mm (0.5 inch) and is commonly used in medium-power transmission systems. With its semicircular tooth profile, it ensures precise synchronization between mechanical components, especially in engine timing systems. Made

from reinforced rubber with fiberglass cords, it offers good resistance to wear, tension, and temperature, making it reliable for demanding mechanical applications.

Dimensions des principales courroies crantées (NF ISO 5294 et 5296)							
type	pas $p$		$h$ mm	$\alpha$ deg.	largeur courroie mm	nombre de dents $Z_c$ longueur primitive courroie $L_p = p \cdot Z_c$	$2a$ mm
	mm	pouces (")					
XL (extra légère)	5,08	1/5 "	2,3	50	6,4 - 7,9 - 9,5	30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90 95, 100, 105, 110, 115, 120, 125, 130	0,508
L (légère)	9,525	3/8 "	3,6	40	12,7 - 19,1 - 25,4	33, 40, 50, 56, 60, 64, 68, 72, 76, 80, 86, 92, 98, 104, 112, 120, 128, 136, 144, 160	0,762
H lourde	12,70	1/2 "	4,3	40	19,1 - 25,4 - 38,1 - 50,8 - 76,2	48, 54, 60, 66, 72, 78, 84, 90, 96, 102, 108, 114, 120, 126, 132, 140, 150, 160, 170, 180, 200, 220, 250, 280, 340	1,372
XH (extra lourde)	22,23	7/8 "	11,2	40	50,8 - 76,2 - 101,6	58, 64, 72, 80, 88, 96, 112, 128, 144, 160, 176, 200	2,794
XXH (extra extra renforcée)	31,75	1" 1/4	15,7	40	50,8 - 76,2 - 101,6 - 127	56, 64, 72, 80, 96, 112, 128, 144	3,048

Figure 27 main toothed belt dimensions.

From figure 27 we have:

(Le pas) Pitch P: **12.70 (mm)**.

(Largeur) Width L: **38.1(mm)**.

(Hauteur) Height H: **4.3 (mm)**.

### III.2.1.6 synchronous belt length :

A synchronous belt's length can be affected by many factors which need to be considered in tandem: tooth pitch, the belt profile, the number of teeth on the belt and distance between pulleys. Belt lengths can be determined using the specific formulas supplied by the belt manufacturer, or by using an online calculator.

$$L = 2 \times a + \frac{\pi}{2} \times (d_1 + d_2) + \frac{(d_1 - d_2)^2}{4 \times a}$$

$$L = 2 \times 600 + \frac{3.14}{2} \times (60 + 120) + \frac{(60 - 120)^2}{4 \times 600} = 1484,1 \text{ mm}$$

L: Length of synchronous belt.

a: Center distance between intermediate sprocket and camshaft.

$d_i$ : Diameter of intermediate sprocket.

$d_2$ : Diameter of camshaft.

### III.2.1.7 pitch length of the synchronous belt :

To calculate the pitch length of the synchronous belt, multiply the number of belt teeth by the tooth pitch.

From figure 23 we have:

We will take  $Z=114$  teeth

$$L_p = pas \times Z = 12.70 \times 114 = 1447,8mm$$

$L_p$ : Original belt length.

Z : Number of synchronous belt teeth.

### III.2.1.8 Frequency of passage:

Passage frequency represents the number of times a given phenomenon (tooth passage, piston stroke, or a specific vibration) occurs within a mechanical system (typically per second). Passage frequency is significant as it serves as a measure of acceptable operating conditions in a dynamic-system study and contributes to assessing whether the mechanical system satisfies accepted frequency ranges to avoid damaging resonance. Passage frequency can be described by the following simple relationship:

$$f = \frac{V}{L}$$

V : the linear velocity (m/s)

L : the characteristic length of the system (m)

Where:

$$V=8.63\text{m/s}$$

$$L=1484.1\text{mm}=1.4841\text{m}$$

$$f = \frac{8,63}{1,484} = 5,81 \text{ Hz}$$

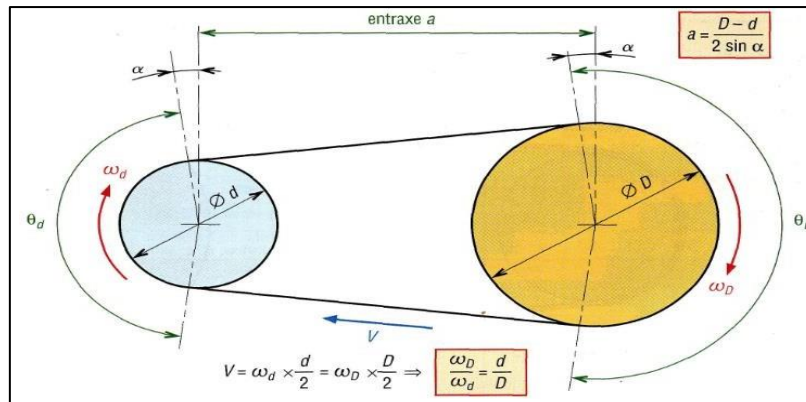
### III.2.1.9 Wrap angle:

The wrap angle, also known as the contact angle, refers to the angle formed by the synchronous belt as it is wrapped around the pulley. This angle is determined by the shape of the pulley and the profile of the belt. The winding angle is important because it affects power transmission, belt life and the overall operation of the drive system. The right angle of wrap ensures good engagement of the belt with the pulley, uniform load distribution and low wear.

$$\theta = \sin^{-1} \frac{(d_2 - d_1)}{2 \times e} = \sin^{-1} \frac{(120 - 60)}{2 \times 75} = 23.57^\circ$$

$$\underline{\alpha}_1 = 180 - 2\beta = 159,96^\circ = 2,8\text{rad}$$

$$\underline{\alpha}_2 = 180 - 2\alpha_1 = 139,92^\circ = 2,44\text{rad}$$



**Figure 28** Wrap angle .

### III.2.1.10 Belt material:

We have chosen glass-fiber-reinforced neoprene as the belt material used in the timing system.

The H type synchronous belt is made from a synthetic neoprene rubber, reinforced with fiberglass cords. The material has good mechanical tensile strength, low elastic deformation and good wear resistance and temperature resistance. These properties are important to retain the timing accuracy of the timing components in the K7M800 engine [35].

Having: for density:  $\rho = 1450 \text{ Kg/ m}^3$

Modulus of elasticity for bending  $E_f = 50 \text{ N/ mm}^2$

Coefficient of friction  $\mu = 0.5$

Allowable stress  $\sigma_{adm} = 10.5 \text{ N/ mm}^2$

### III.2.1.11 Sollicitations subies par la courroie :

Belts are subjected to a variety of stresses when used in a drive system.

The tangential force, referred to as tangential tensile force, is the force applied by the synchronous belt along its contact section with the pulley. The tangential force is parallel to the belt surface and is in the direction of the belt movement.

The tangential force creates power transmission across the drive system pulleys. This force is caused by belt tension and the coefficient of friction the belt has against the pulley. The tangential force must overcome slippage and provide power transmission.

$$F_t = \frac{P_e}{V} = \frac{15410}{8,635} = 1842,19N$$

$F_t$  : Tangential force.

$P_e$ : Effective power.

V: Linear velocity.

**We have the Euler equation :** 
$$\frac{T_1}{T_2} = e^{\mu \times \alpha_2} \dots \dots \dots (1)$$

And: 
$$T_1 = F_t \times \frac{e^{\mu \times \alpha_2}}{e^{\mu \times \alpha_2} - 1} \dots \dots \dots (2)$$

$$T_1 = 1842,19 \times \frac{e^{0,5 \times 2,44}}{e^{0,5 \times 2,44} - 1} = 2613,88 N$$

According to equations(1) and (2) : 
$$T_2 = \frac{T_1}{e^{\mu \times \alpha_2}} = \frac{2613,88}{e^{0,5 \times 2,44}} = 771,69 N$$

$T_1$ : Tight strand tension

$T_2$ :Slack strand tension

**III.2.1.12 Tensile stress :**

Tensile stress refers to the tension force exerted on the belt to maintain adequate power transmission between the drive system pulleys. It represents the force exerted by the belt to resist the load and transmit power efficiently.

$$\sigma_T = \frac{T_1}{\Delta}$$

$$\Delta = b \times H = 76,2 \times 4,3 = 327,66 \text{ mm}^2$$

$$\sigma_T = \frac{2613,88}{327,66} = 7,97 \text{ N/mm}^2$$

A: cross-sectional area in ( $\text{mm}^2$ )

b: belt width in (mm)

H: belt thickness in (mm)

$T_1$ : tension of tensioned strand

### III.2.1.13    **Contrainte due à la force centrifuge :**

As the belt rotates, each point on the belt experiences a centrifugal force directed outwards, perpendicular to the direction of rotation.

This centrifugal force generates a stress that attempts to stretch the belt radially outwards.

Centrifugal force stress depends on belt speed and distance from the axis of rotation. The higher the speed and the greater the distance from the axis, the greater the centrifugal force.

$$\sigma_c = \rho \times V^2 = 1450 \times (8.635 \times 10^{-3})^2 = 0,108 \text{ N/mm}^2$$

$\rho$ : Density  $\text{KG} / \text{m}^3$

V: Tangential velocity m/s

### III.2.1.14    **Bending stress on the belt:[6]**

Belt bending stress refers to the stress exerted on a belt when it is subjected to bending around a pulley. As the belt passes over a pulley, it undergoes a curvature that can generate stresses in the belt section in contact with the pulley.

$$\sigma_F = E_f \times \frac{e}{d_i} = 50 \times \frac{1,59}{60} = 1,325 \text{ N/mm}^2$$

$E_f$ : Yield strength in  $\text{N/mm}^2$

e: Belt thickness without teeth in mm

$d_i$ :Diameter of small pulley in mm

### III.2.1.15 Maximum belt stress $\sigma_{\max}$ :

Maximum belt stress is usually expressed in terms of maximum tension, i.e. the maximum force the belt can withstand before breaking.

$$\sigma_{\max} = \sigma_T + \sigma_c + \sigma_F = 7,79 + 0,108 + 1,325 = 9,403\text{N/mm}^2$$

For the chosen belt material we have :  $\sigma_{\text{adm}} = 10,5\text{N/mm}^2$

$$\sigma_{\max} = 9,403\text{N/mm}^2 < \sigma_{\text{adm}} = 10,5\text{N/mm}^2$$

The resistance condition is therefore verified.

Once we have dimensioned the main mechanical elements of the variable valve timing system, the timing belt, the valves, the return springs, and the camshaft, we now re-focus our attention on a key element that facilitates the real-time variation of valve timing that we are presenting: the cam phaser.

The camshaft in our assignment was designed to follow the crankshaft motion, and therefore our timing belt was dimensioned accordingly with respect to torque transfer capability and mechanical stability. However, fixed valve timing cannot maximize engine performance during all operating conditions. The cam phaser, which is a device that allows angular displacement of the camshaft with respect to the crankshaft, will alleviate this constraint.

The cam phaser allows a degree of control over the timing of valve actuation at the time of engine operation, thereby creating a device that will enhance the power available, the fuel efficiency, and the success of emission control settings during varying engine speeds.

### III.2.2 Camshaft dimensioning:

### III.3 Cam phaser:

A cam phaser is a mechanical device, typically hydraulic, mounted on the end of the camshaft in modern internal combustion engines. Its main function is to adjust the angular position of the camshaft relative to the crankshaft, thereby altering the timing of the opening and closing of the engine's intake and exhaust valves. This adjustment is crucial for optimizing engine performance, efficiency, and emissions under varying driving conditions [36].



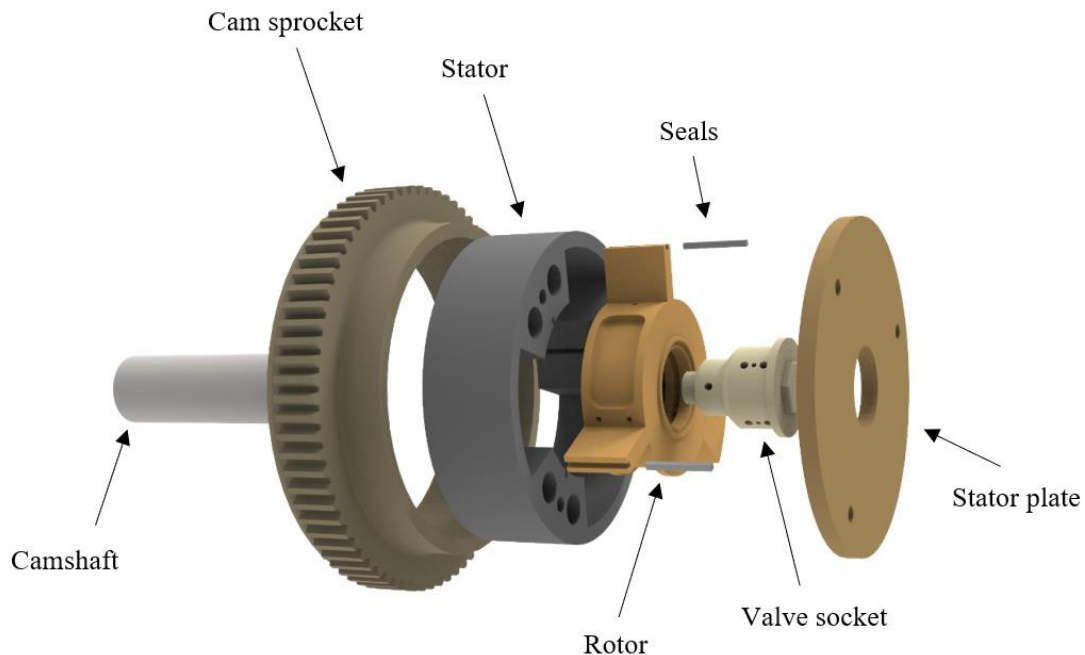
**Figure 29** cam phaser [38].

#### III.3.1 Description of cam phaser:

The cam phaser functions in the following way: it varies the position of the camshaft with respect to the crankshaft using hydraulic means. Oil enters the phaser through a solenoid operated oil control valve (OCV) which controls oil flow to the phaser based on signals received from the ECU. Inside the phaser, a rotor is fastened to the camshaft and a stator fastened to the timing gear. When oil pressure is applied to one vane of the rotor, the rotor (and hence camshaft) rotates slightly, either advancing or retarding the camshaft position. This rotational movement modifies the valve timing without affecting cam lift or duration. The ECU continually alters this position in real time based on engine conditions, including RPM, engine load, engine

temperature and throttle position. By manipulating the camshaft position, the ECU can advance or retard the intake event to optimize engine performance, improve fuel efficiency, reduce emissions and improve drivability.

The cam phaser is the main actuator in Variable Valve Timing (VVT) systems and is made up of various components that create a series of connected parts to achieve the dynamic adjustment of the camshaft phase. The cam sprocket rotates from either the timing belt or chain, delivering rotational movement to the stator which is the fixed outer body of the phaser. The rotor, which is rigidly connected to the camshaft, rotates within the stator. The hydraulic pressure is supplied

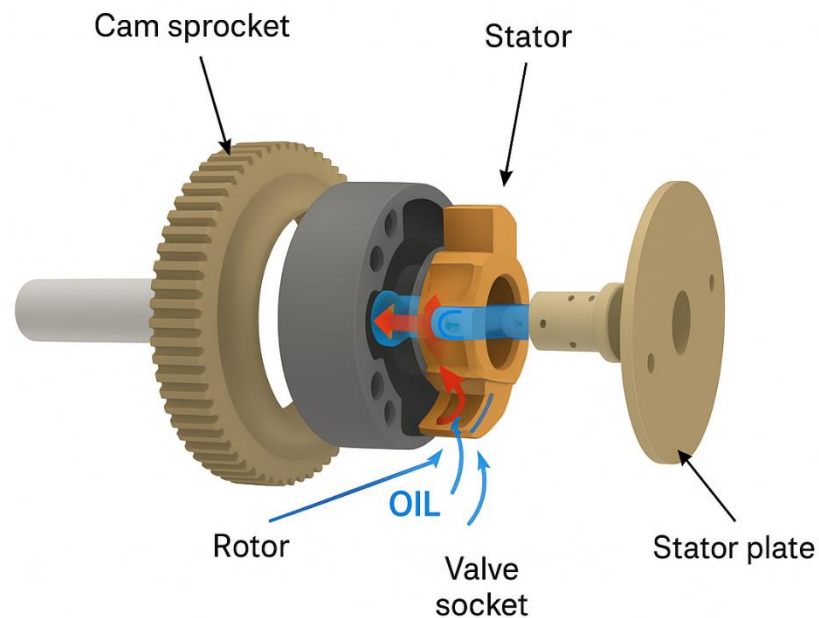


**Figure 30** Cam phaser modeled in SolidWorks [40].

via the valve socket and oil is delivered into the chambers separated by seals, generating a torque which advances or retards the camshaft angle from the crankshaft. The stator plate provides rigidity to the structural components, and provides proper sealing in the assembly.

The VVT system directs these components to accurately change the timing of valve opening and closing events based on engine load and speed. At low rpm, the phaser can advance the valve timing to improve both torque and cylinder filling; while at high rpm the phaser can retard

the timing to minimize overlap while maximizing power. This combination of mechanical components, along with hydraulic control, gives the engine the ability to operate more efficiently over a larger range of conditions, leading to ideal engine functioning, reduced fuel usage, and lower emissions.



**Figure 31** oil flow in the cam phaser adjusts the camshaft position [40].

The actual mechanism that adjusts the angle of the camshaft from the crankshaft in a Variable Valve Timing (VVT) cam phaser is the controlled movement of engine oil under pressure. At its most basic level, the engine oil is routed through a control valve (most commonly, an oil control valve, or simply a solenoid) to chambers in the phaser body. When oil is directed to one side of the rotor vanes, the rotor pushes in the direction of the camshaft to advance valve timing; when oil is directed to the opposite side, the camshaft is rotated in the opposite direction to retard timing. The stator is connected to the cam sprocket, and it remains firmly fixed to the timing belt drive, while the rotor (connected to the camshaft) is able to rotate slightly to align with the difference in oil pressure inside the specified chamber. To maximize the efficiency of the hydraulic chambers, seals are installed to separate each hydraulic chamber so that pressure can build. The ECU (Engine Control Unit) can adjust camshaft phasing because it meters the flow rate of the oil, which allows the ECU to balance optimum cylinder filling, torque, fuel

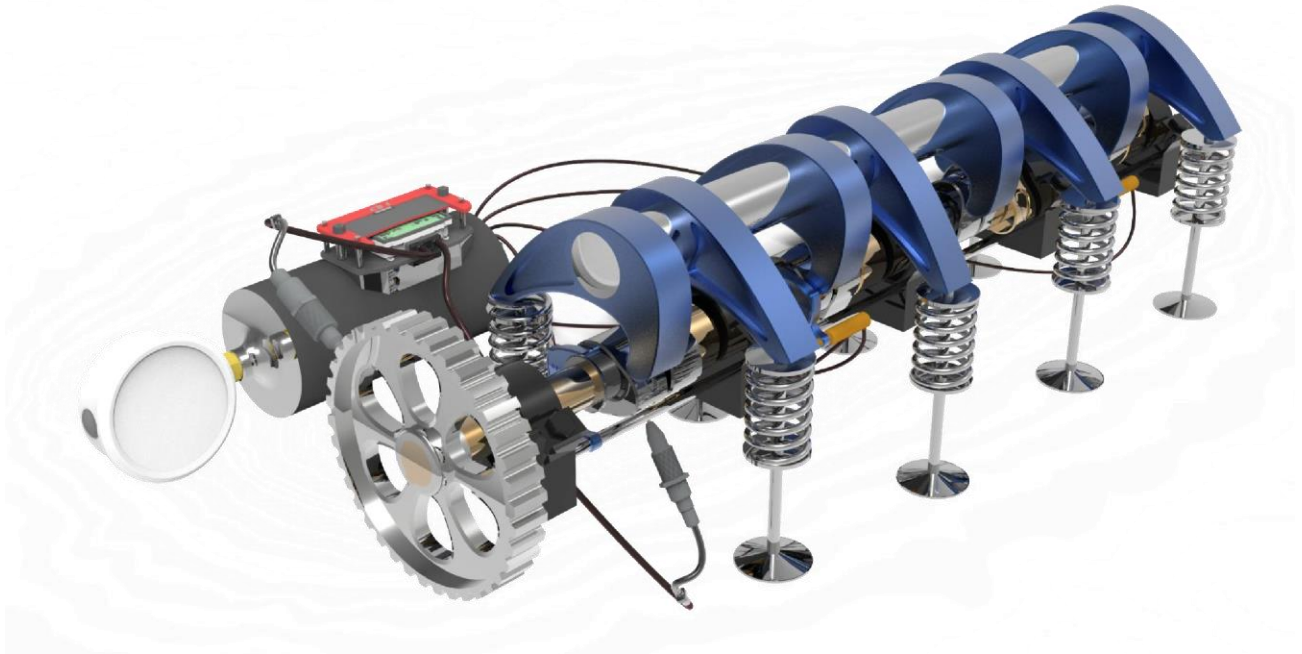


### **III.4 Conclusion :**

In this chapter we performed the dimensioning of the belt drive and the variable cam phaser system. This step allowed to determine the relevant geometric and mechanical parameters (primitive length, wrap angles, transmission ratios, phaser characteristics, etc.) to ensure the system is physically feasible.

These results constitute the necessary foundation for the next step. Indeed, once dimensions and parameters are determined, it will become possible to numerically simulate the camshaft behavior to analyze the impact of variable valve timing on performance.

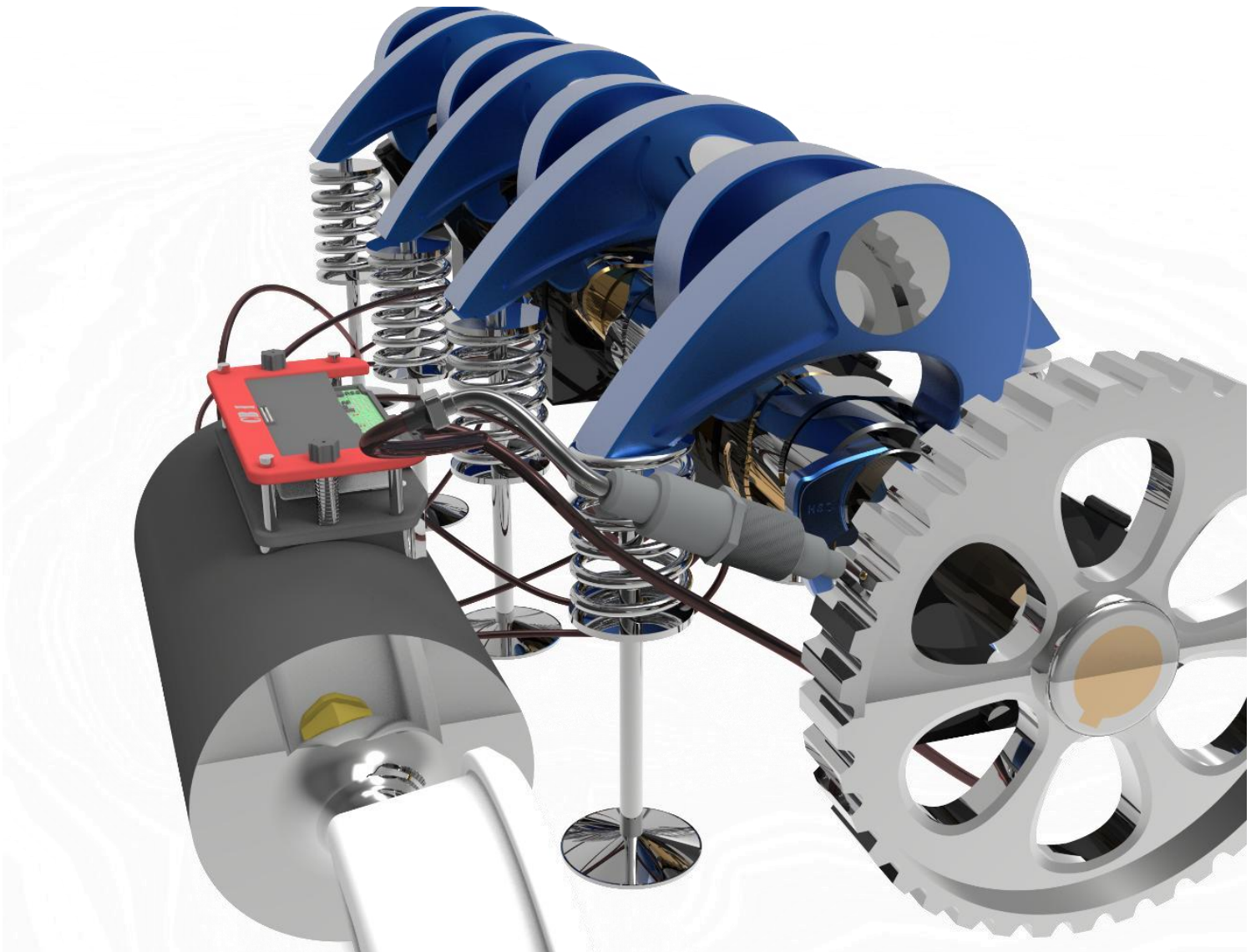
## Chapter IV: Simulation



**Figure 33** Conceptual design o variable valve timing distribution system [40].

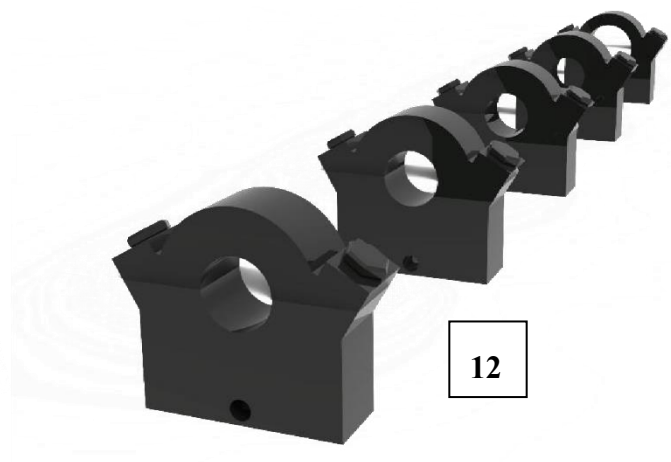
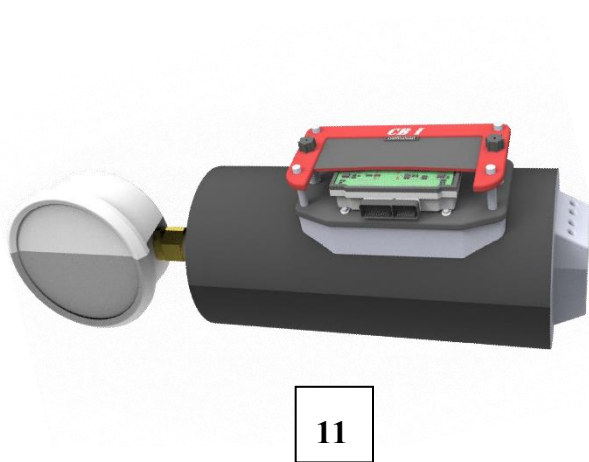
### IV.1 Descreption of the system:

This thesis set out to explore the importance of different variable distribution systems and their role in improving engine efficiency, reliability, and above all, increasing power output from relatively modest engines such as the Renault K7M800. After months of research and detailed calculations, we were able to design a variable distribution system fully compatible with this engine. The result is arguably one of the simplest and most efficient VVL systems conceived to date. It delivers increased power at higher RPMs while ensuring maximum fuel efficiency at lower RPMs, which are typically associated with city and urban driving. At the same time, it maintains the compact size of the original 1.6L displacement engine and preserves its ease of repair.



**Figure 34** Another view, Conceptual design o variable valve timing distribution system [40].

IV.1.1 Systeme component:

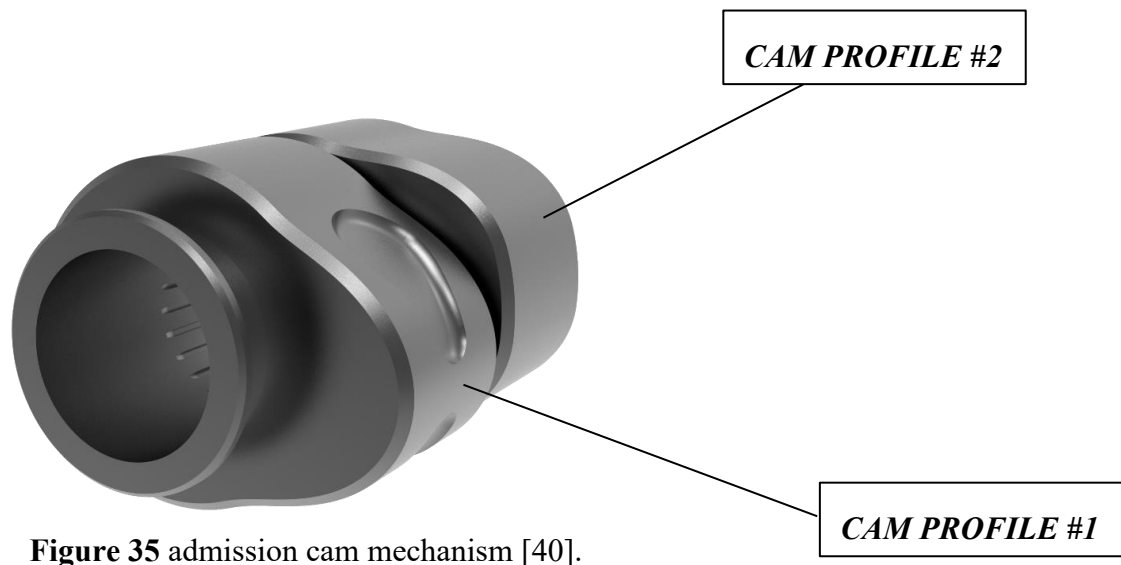




Those pictures all modeled by us in SolidWorks [40].

**Table 2** system component and materials

No.	Component	materials
1	Admission cam mechanism (2 cam lobes)	Hardened steel sleeve (42CrMo4)
2	Intake rocker arm	Forged alloy steel (42CrMo4)
3	Valve spring	High-alloy spring steel (SiCr (SUP9))
4	Valve spring	High-alloy spring steel (SiCr (SUP9))
5	Valve	Martensitic stainless steels (X45CrSi9)
6	Camshaft sprocket	Forged alloy steel (42CrMo4)
7	Exhaust cam mechanism	Forged alloy steel (42CrMo4)
8	Fork assembly (to switch between cam profile)	carburizing steel (20MnCr5)
9	Actuator	Forged alloy steel (42CrMo4)
10	Exhaust rocker arm	Forged alloy steel (42CrMo4)
11	OIL unit controller	-----
12	Camshaft supports (housing + bushings)	EN-GJL-250 (gray cast iron)+CuPb10Sn (copper-lead bronze alloy)
13	Rotational speed sensor	-----
14	CAM Position sensor	-----



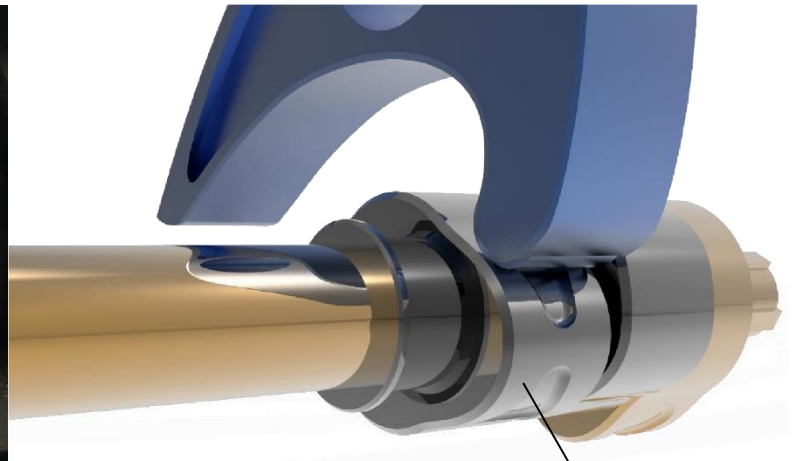
**Figure 35** admission cam mechanism [40].

The **admission cam mechanism** is a specialized component consisting of two cam lobes, each with distinct cam profiles, mounted on the same axis. The mechanism is designed to slide over the exhaust camshaft through precisely machined grooves on both parts, ensuring a smooth and controlled linear transition between the two lobes.

Each cam profile corresponds to a specific driving mode. The **first cam profile** operates at engine speeds between **1,500 and 3,000 RPM**, featuring shorter valve opening and closing durations. This configuration is optimized for urban driving conditions, where reduced valve overlap improves fuel efficiency and contributes to engine durability. In contrast, the **second cam profile** provides extended valve opening intervals, allowing a greater volume of air to enter the combustion chamber. This increases the engine's volumetric efficiency and enables higher power output, making it more suitable for highway driving and sustained high-speed operation.



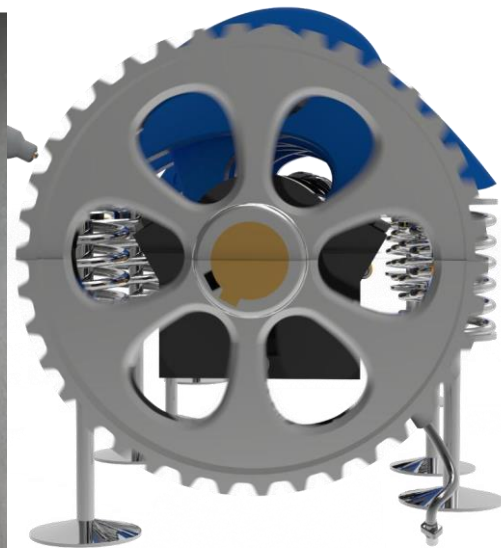
**Figure 36** Engine Tachometer Display (x1000 RPM) [41].



**CAM PROFILE #1  
UNDER WORKING  
ORDER**

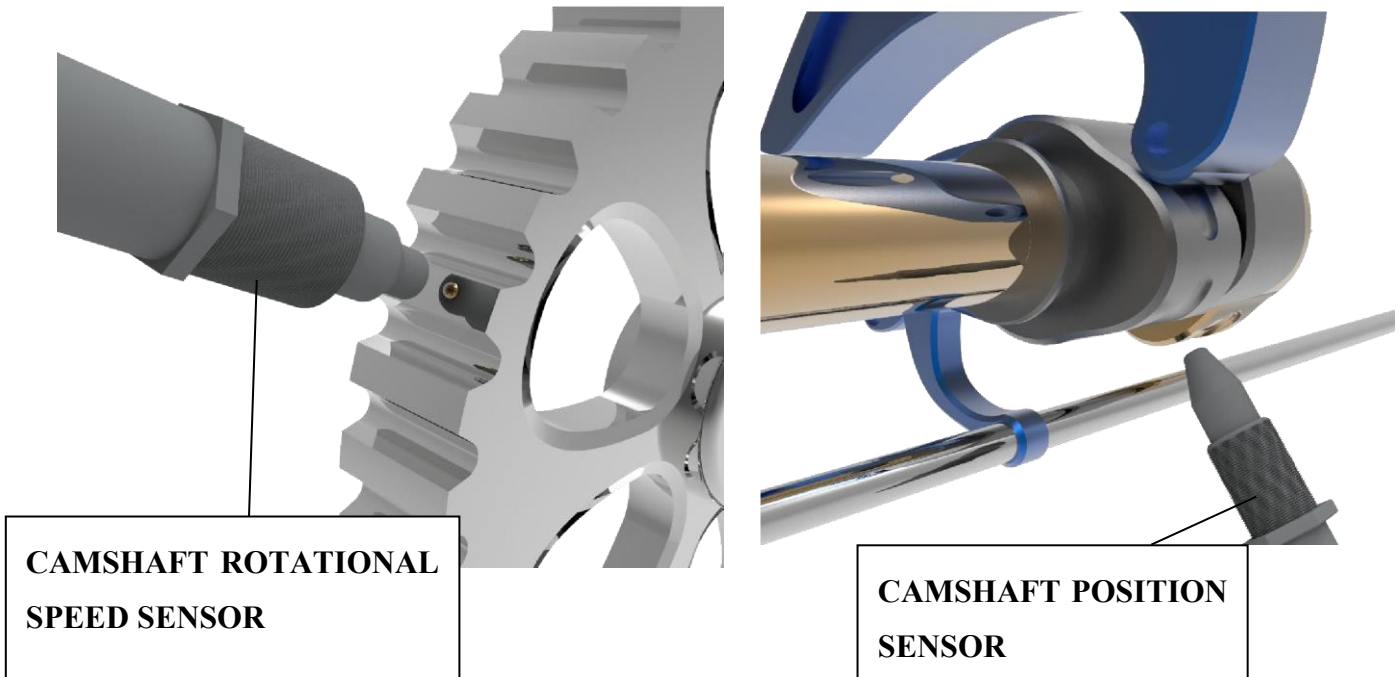
**Figure 37** cam profile #1 under working order [40].

- 1- At idle and low to medium engine speeds, cam profile #1 actuates the intake rocker arms, thereby controlling valve timing to maintain stable combustion and optimize fuel efficiency.



**Figure 38** Accelerating [40] [43].

- 2- When the accelerator pedal is pressed, the throttle opens to allow a greater volume of air into the intake manifold, increasing the engine's rotational speed (RPM). Since the camshaft sprocket is directly driven by the engine's crankshaft, its rotational speed rises proportionally as well.



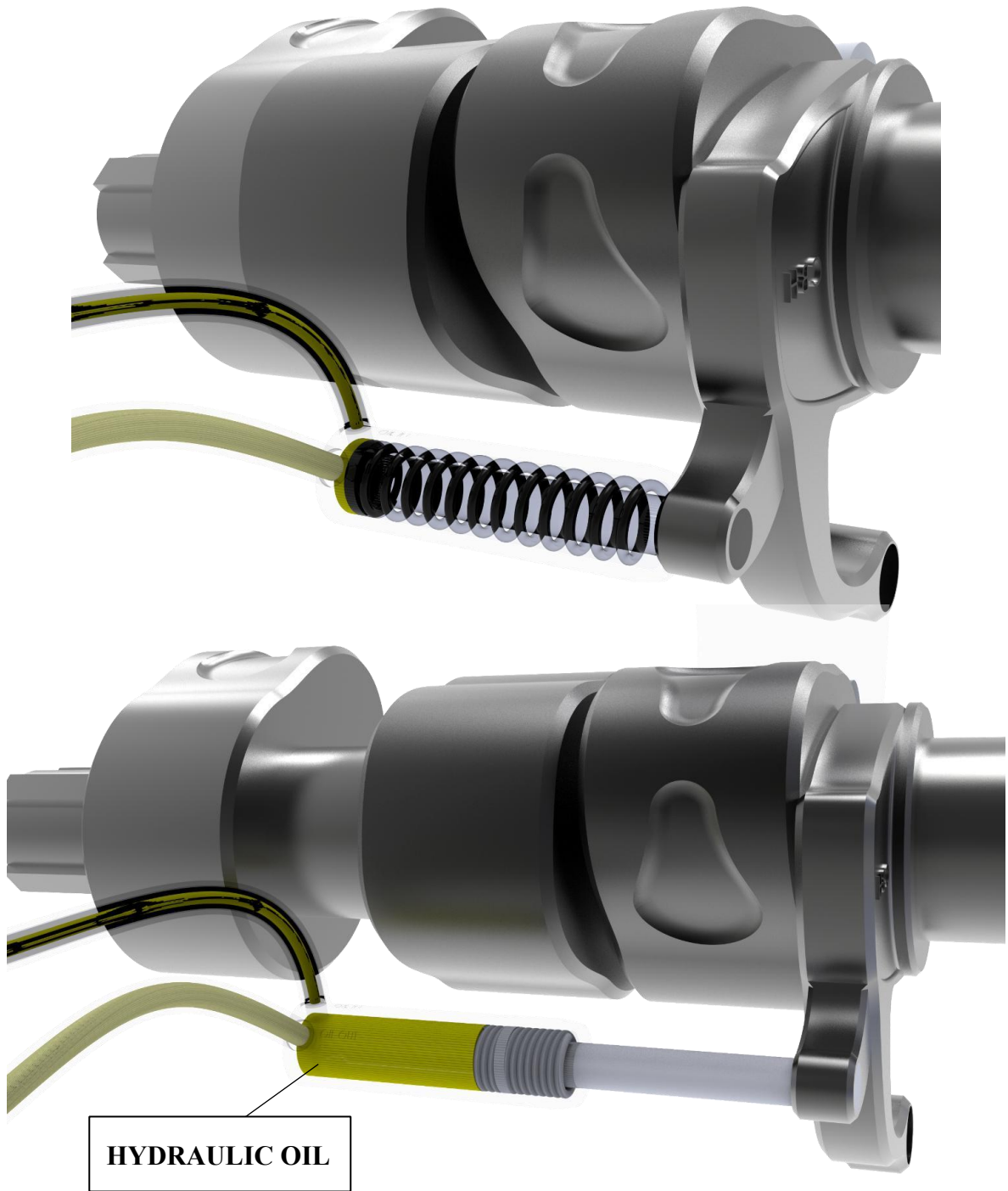
**Figure 39** Sensor placements and types [40].

- 3- As engine speed increases, two sensors coordinate the operation of the mechanism. The camshaft speed sensor detects the rise in rotational velocity, while the cam lobe position sensor identifies the angular position of the camshaft relative to the crankshaft. Together, these inputs determine the precise moment at which the mechanism transitions between cam profiles.



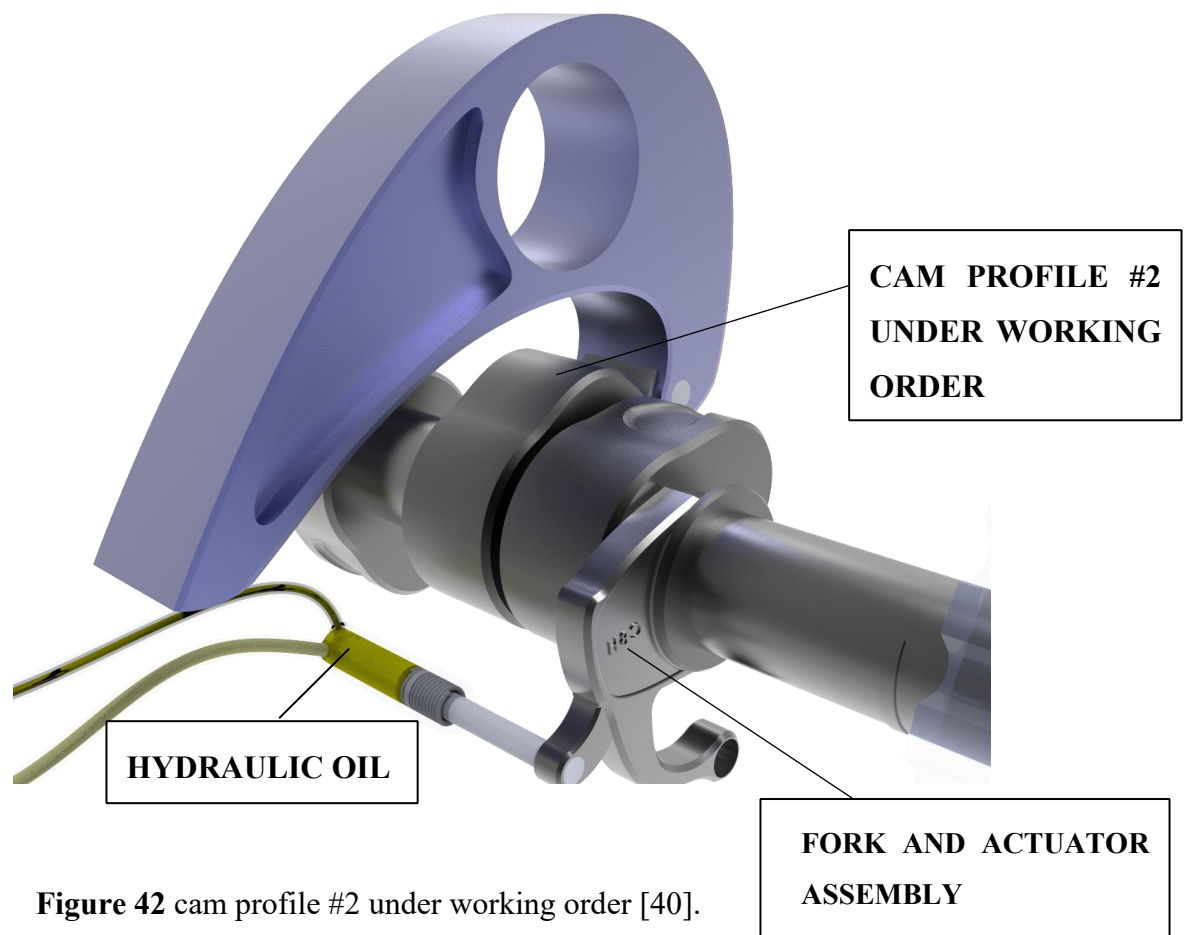
**Figure 40** OIL unit controller [40].

- 4- The information from both sensors is transmitted to an oil control unit integrated with an electronic control unit (ECU). The ECU processes the incoming data, calculating the precise engine conditions required for a profile change. Based on these calculations, the oil control unit directs pressurized oil to a set of actuators linked to a fork assembly. This fork assembly is responsible for engaging or disengaging the cam lobes, enabling smooth and controlled switching between cam profile #1 and cam profile #2.



**Figure 41** overview of the workarounds of the actuator and fork assembly [40].

- 5- The ECU commands the oil control unit to channel pressurized oil into the actuator chamber, where hydraulic force displaces the piston and drives the fork assembly in a linear motion. This movement shifts the cam mechanism from profile #1 to profile #2, enabling the transition to a higher-lift configuration. As soon as the hydraulic pressure is released, the return spring inside the actuator restores the mechanism to its default state, smoothly re-engaging cam profile #1 without mechanical shock. . In this process, the rocker arms experience a distinct change in motion: under profile #1 they transmit a shorter valve lift with reduced duration, favoring combustion stability and efficiency at lower speeds, whereas under profile #2 they follow a higher lift with extended duration, allowing increased airflow into the combustion chamber and consequently enhancing volumetric efficiency and power output at elevated engine speeds.

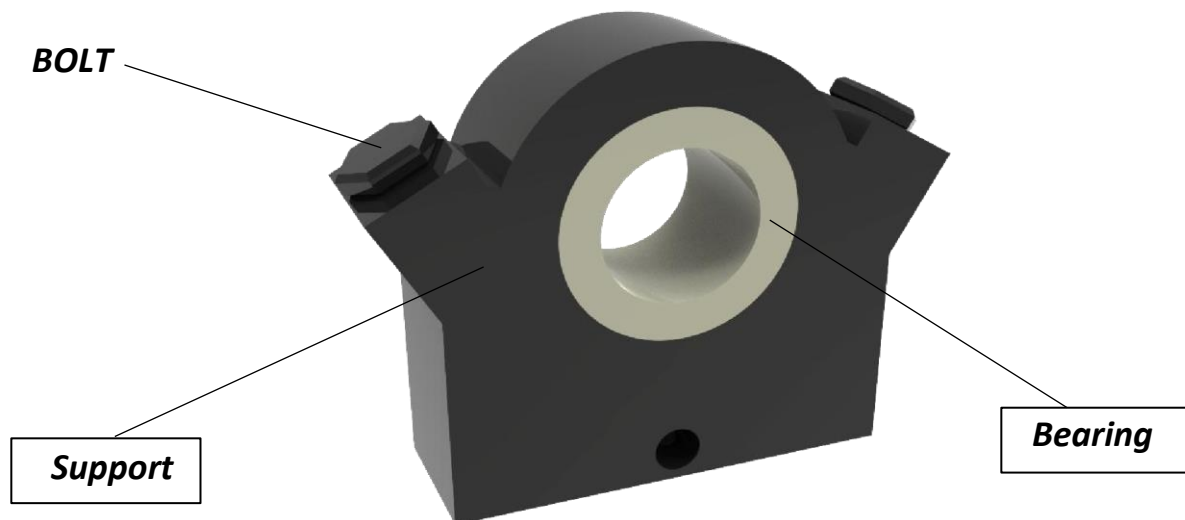


**Figure 42** cam profile #2 under working order [40].

- 6- With cam profile #2 engaged, the operation of the actuator–fork assembly must remain synchronized with the engine’s firing order. For this four-cylinder engine, the sequence is 1-3-4-2. This means that each actuator and its corresponding cam mechanism must transition in phase with the cylinder that is about to enter its intake stroke. Proper alignment ensures that only the intended intake valves receive the increased lift and extended duration provided by profile #2, while the other cylinders continue their cycles without interference.

If the actuator sequence were not matched to the firing order, valve timing would become erratic, leading to premature or delayed valve opening. Such misalignment would reduce volumetric efficiency, cause unstable combustion, and in severe cases create mechanical conflict between valves and pistons. By adhering to the 1-3-4-2 order, the system guarantees that airflow enhancement occurs cylinder by cylinder in the correct rotational sequence of the crankshaft, maintaining smooth power delivery and mechanical balance across the engine.

### IV.2 Support :



**Figure 43** Support [40].

The camshaft is supported in plain journal bearings in the cylinder-head support. The support housing is made of EN-GJL-250 (pearlitic gray cast iron) for dimensional stability and vibration damping; an alternative lightweight option is AlSi10Mg, with pressed-in steel/bronze bearing seats. The bearing shells consist of a tri-metal design (steel backing, CuPb bronze intermediate layer, thin soft overlay) that provides stiffness and load carrying capacity, as well as a comfortable running surface. The camshaft journals are made of forged 42CrMo4 and are treated surface (induction hardened or nitrided) and superfinished to achieve a stable hydrodynamic oil film. Continuous lubrication and cooling is achieved with oil grooves and oil feed holes in the housing and journals. The material/processing combination provides low friction, high fatigue life, and predictable wear behavior under engine loads.

### **IV.3 Code :**

In the course of this work, finite element analysis of the camshaft assembly was initially attempted using SolidWorks Simulation and Abaqus. However, both platforms exhibited limitations in managing the highly intricate geometry, multiple nonlinear contact interfaces, and the fine meshing requirements of the mechanism. These constraints led to convergence issues and inadequate representation of localized stress fields. Consequently, the study transitioned to ANSYS Workbench R1, whose advanced meshing algorithms, adaptive refinement, and robust nonlinear solvers provided the necessary computational framework. The platform allowed for accurate definition of contact pairs, load transfer through bearing supports, and dynamic boundary conditions, thereby enabling a reliable structural evaluation of stresses, deformations, and fatigue-critical regions. This shift not only ensured the validity of the analysis but also fostered a deeper technical proficiency in the use of ANSYS as a high-fidelity simulation environment for complex mechanical systems.

## IV.4 MESH (Maillage) :

### Mesh Selection: Triangular Elements

A triangular mesh is utilized in this analysis due to the complexity of the camshaft geometry, which has multiple curved lobes, fillets, and transitions. Triangular elements are more suitable for irregular shapes and curved boundaries and represent the geometry in a more accurate way than structured quadrilateral or hexahedral elements alone.

In addition, triangular elements can improve the flexibility of the mesh refinement. Triangular elements enable the mesh to be finer in specific areas of interest, such as the areas around the cam lobe tips and fillets, where stress concentrations may occur, compared to the shaft body, which is much less critical. This ultimately leads to more accurate stress and deformation predictions without drastically increasing computational expense.

Overall, triangular meshes allow for the realistic modeling of the camshaft's complex geometry. In addition, it helps ensure that the finite element analysis (FEA) accurately captures the increased local effects from deformation at the cam tips and multi-axial stress concentrations from the fillets.

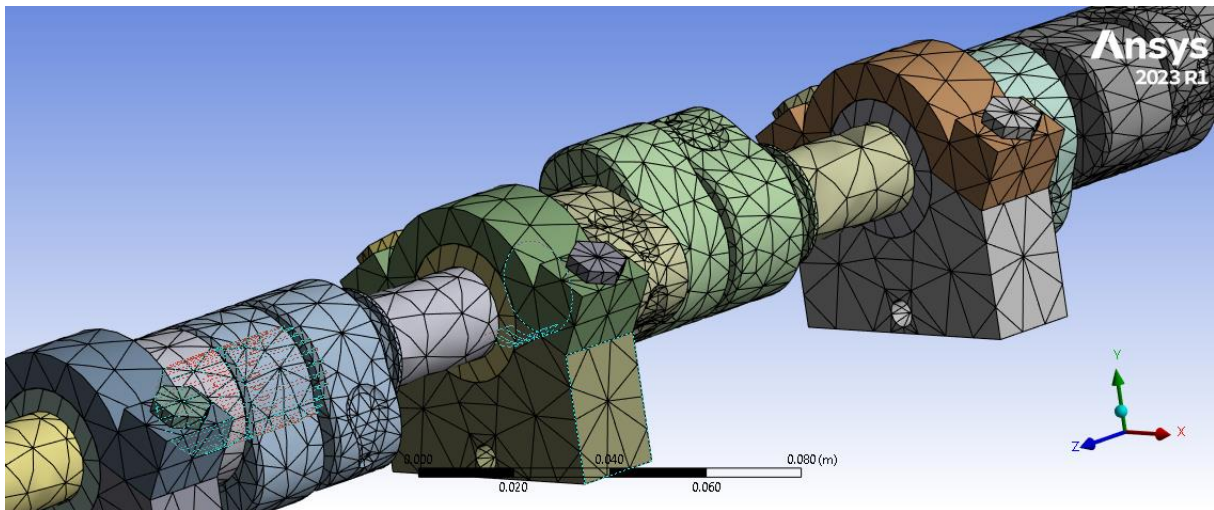
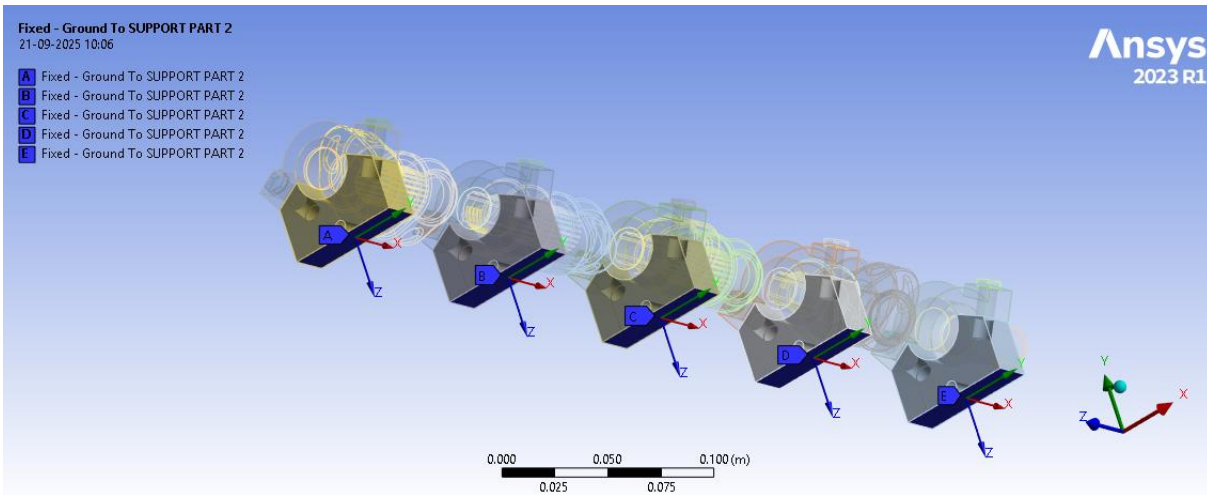


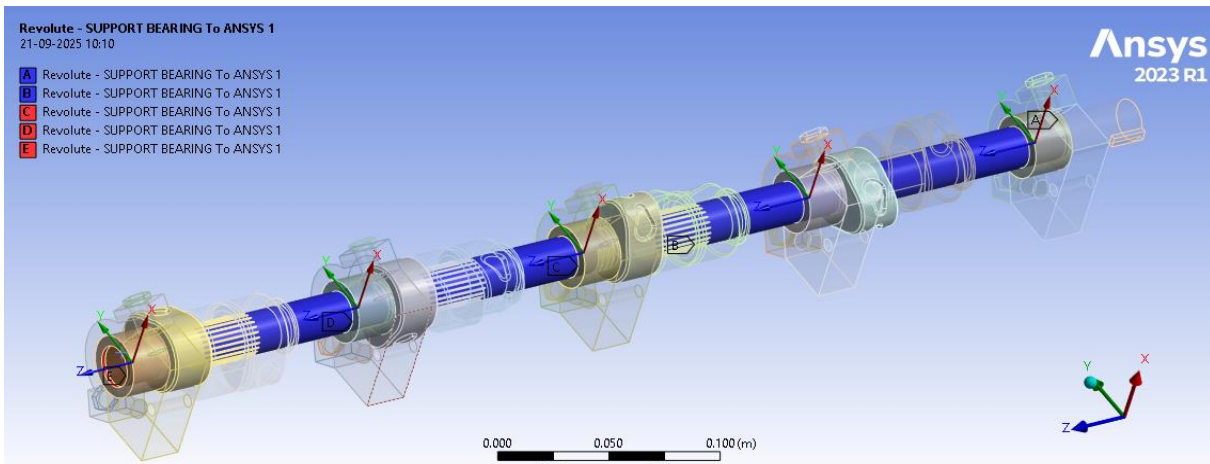
Figure 44 mesh [44].

## IV.5 Boundary conditions:



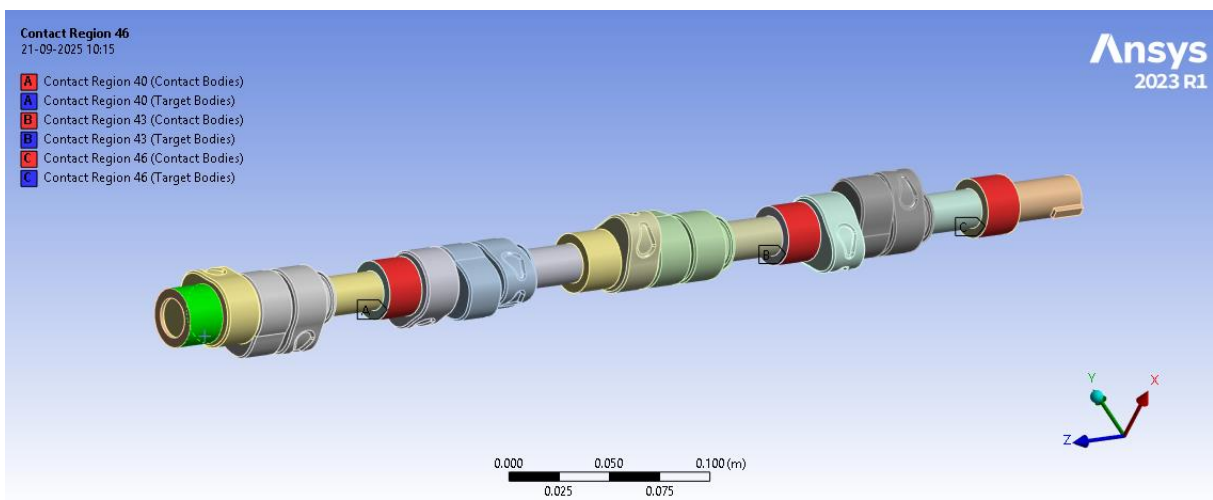
**Figure 45** fixed ground boundary condition[44].

In this simulation, the regions labeled A, B, C, D, and E were defined using the boundary condition Fixed - Ground to Support PART 2. This boundary condition fully constrains the regions of interest surfaces, eliminating both translational and rotational degrees of freedom. This is analogous to the actual supports of the camshaft in the engine block, where the camshaft is held in position by its bearings. Fixed boundary support provides model numerical stability and simulate realistic boundary conditions allowing kinematic behavior of the camshaft to be analyzed correctly when the camshaft is rotated.



**Figure 46** reevaluate boundary condition [44].

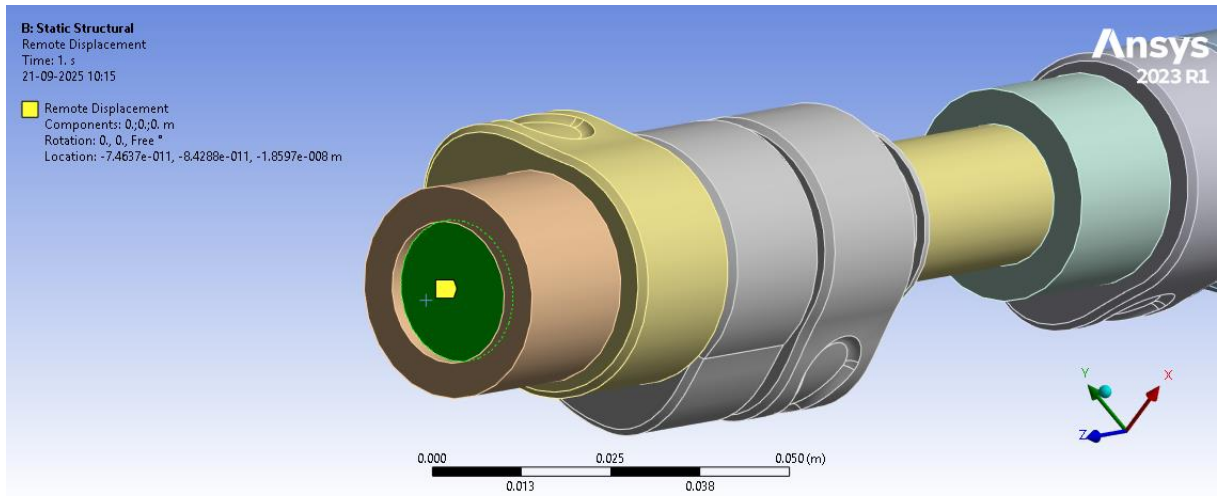
In this model, regions labeled A, B, C, D, and E were defined with the boundary condition Revolute - SUPPORT BEARING to ANSYS 1. This type of constraint will allow components to rotate about a defined axis while preventing all translational movements. This mechanism is simulated as it demonstrates the real function of camshaft bearings, which are inside an engine and support the shaft both radially and axially while allowing it to freely rotate about its longitudinal axis. Locating revolute supports at various locations along the camshaft simulates a realistic boundary condition representative of the actual mounted condition of the shafts, while permitting a realistic rotational motion for analysis of dynamic response.



**Figure 47** contact region boundary condition [44].

For the simulation, a few of contact regions were defined as parts of the motion physics of camshaft parts. Regions labeled with A, B, and C are considered contact–target pairs with one contact body and one target body, allowing ANSYS to accurately model the transfer of force and relative motion at each contact interface. The proper definition of the contact regions permits the assembled parts to perform as they would in reality when they are functioning as part of the camshaft system. The contact regions were important in obtaining the mechanical

relationship or interaction of the components of the camshaft,, bearings, and phaser in a reliable and accurate way of the simulation results.

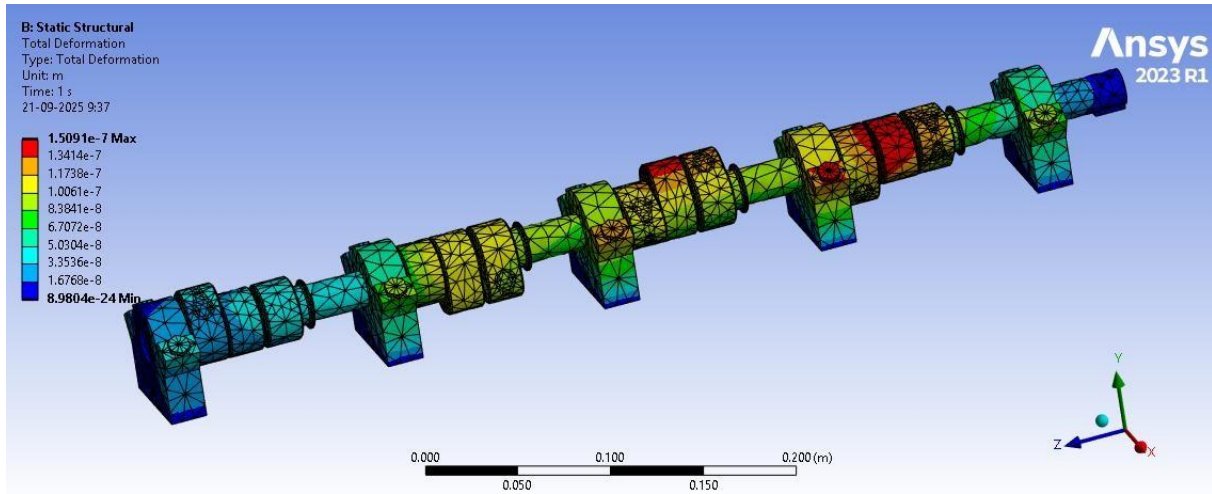


**Figure 48** Static structural boundary condition [44].

In this simulation, a remote displacement boundary condition was applied to constrain the motion of one end of the shaft assembly. The highlighted face was assigned as the region of influence, while the displacement was defined at a remote point in space. The translational degrees of freedom ( $X$ ,  $Y$ ,  $Z$ ) were fully restricted, preventing any linear movement of the shaft end. The rotational degrees of freedom about the  $X$ - and  $Y$ -axes were also constrained, while rotation about the  $Z$ -axis was left free. This setup replicates realistic operating conditions, where the shaft is fixed against translation and tilting but allowed to spin about its longitudinal axis. By defining the boundary condition in this way, ANSYS ensures that the simulated structural response captures the actual support and loading scenario of the shaft, thereby enhancing the fidelity of the analysis results.

## IV.6 Result and intervention :

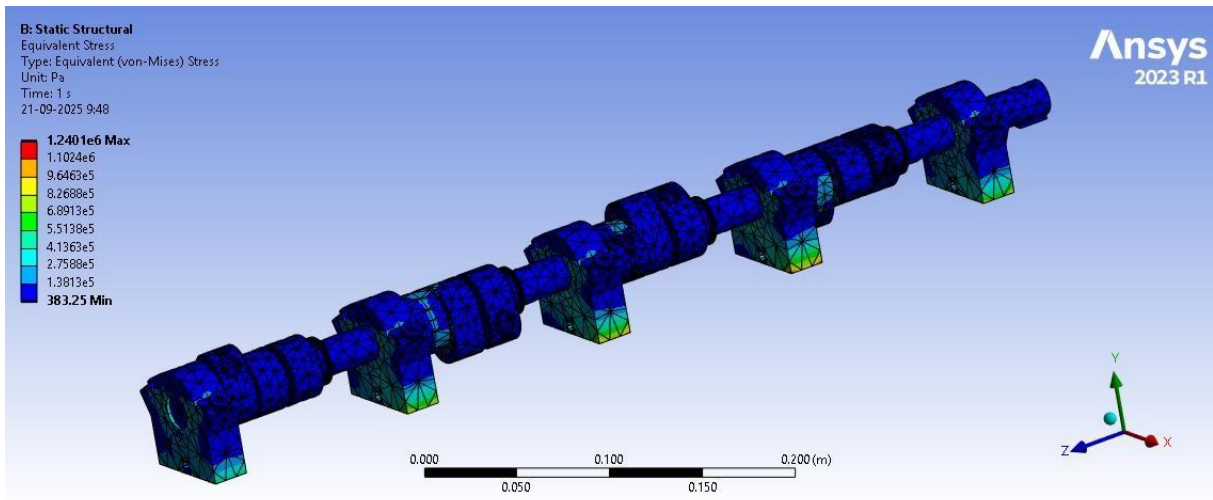
### IV.6.1 Total Deformation :



**Figure 49** total deformation simulation and result [44].

According to the analysis, the maximum deformation was approximately  $1.5 \times 10^{-7}$  m (0.15 microns); a very small value and indicative of adequate structural stiffness of the camshaft experiencing applied loading conditions. The locations of maximum deformation were the cam lobe tips where the interface conducting the loading occurs with the valve followers (tappets or rocker arms). The deflection or displacement occurs in this local manner due to the action of the valve spring force through the follower, which keeps the cam in continuous contact and loading the follower at a point on the cam, producing concentrated loading action at a certain point of the cam. This also is conditional on the camshaft design, as the cam lobe tips lie at the greatest radial distance from the neutral axis of bending or deflection and will thus displace the most (the lobe tips will displace more than the camshaft body or journal regions). The shaft body and journal regions are less deformed because these members are supported to prevent or limit displacements in these regions.

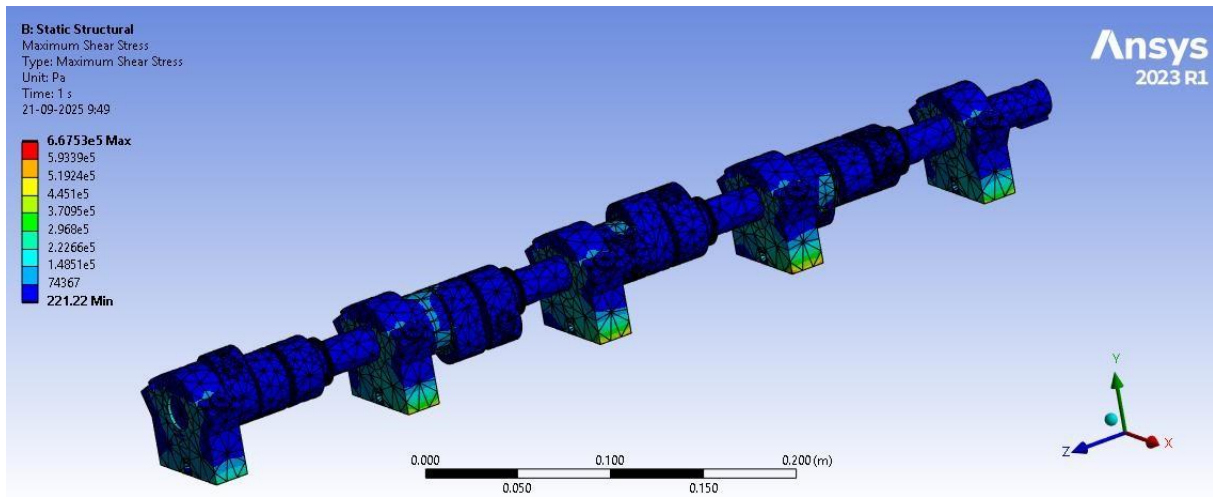
## IV.6.2 Equivalent Stress (von Mises):



**Figure 50** von-misses stress simulation and result [44].

The maximum von Mises stress recorded in the simulation was approximately  $1.24 \times 10^6$  Pa (1.24 MPa), which is considerably lower than the yield strength of conventional camshaft steels, typically ranging from 250 to 600 MPa. This demonstrates that the camshaft operates with a substantial safety margin under the given loading conditions. The regions of elevated stress were primarily located at the fillets of the cam lobes and journals, which act as natural stress concentrators due to geometric discontinuities. Nevertheless, the stress magnitudes in these areas remain far below the material's yield threshold, confirming the structural adequacy of the design. In contrast, the main shaft sections exhibited stress levels predominantly within the blue range (below 500 kPa), reflecting the effective load distribution through the supporting bearings and the relatively low demand on these regions.

### IV.6.3 Maximum Shear Stress:



**Figure 51** shear stress simulation and result[44].

The maximum shear stress seen in the analysis was around  $6.67 \times 10^5$  Pa (0.67 MPa). It generally tracked the von Mises stress distribution, with stress also appearing to peak at the edges of the cam lobe and fillet region, where the effects of combined bending and torsion will be greatest. Even with these stress peaks, the stress is still extremely low in comparison to the shear strength of common camshaft steels (more than 300 MPa), and proves the design is very robust. On a larger level, the deformation results show that a practical amount of deflection occurred, which also should not be of any concern regarding permanent deformation in service conditions. In addition, the red zones at the lobe tips are not representative of any critical structural issues, but rather the localized action of the valve spring force. Finally, the von Mises and shear stress values are relatively low in comparison to typical material limits, resulting in a high safety margin. The analysis overall concludes that the entire camshaft structural design is mechanically sound, with only minor stress concentrations at the lobe tips and fillet area, none of which present a structural failure risk.

## **IV.7 Conclusion:**

This chapter has concluded an extensive finite element analysis of the camshaft in order to assess its structural performance under operation loads. The results showed that the largest deformation was approximately  $1.5 \times 10^{-7}$  m, which is a negligible value indicative of the relatively high rigidity of the component. The highest displacement regions were at the cam lobe tips, appropriately positioned as this was the area with the greatest distance from the neutral axis and which experienced localized loading from the valve spring.

Similarly, examining the von Mises stress distribution, the maximum von Mises stress was close to 1.24 MPa and the maximum shear stress was a maximum of 0.67 MPa. Both of these values are extremely low when compared to yield and shear strengths of conventional camshaft steels, which are above 250 and 300 MPa, respectively. The stress concentrations at the lobe fillets and journal transitions were anticipated due to being geometric discontinuities, but even in these areas stresses were far below material throw limits.

In summary, the simulation validated that the design of the camshaft is both mechanically valid and safe, with a very high safety margin. No risks of plastic deformation or structural failure were found in the applied boundary conditions. Ultimately, this demonstrates the strength of the camshaft design for the configuration tested, while also providing a good basis for future optimization and performance assessments of the variable valve timing system.

## **General conclusion and recommendation**

This work examined and developed the steps to incorporate a variable valve timing (VVT) system into the K7M800 engine. We discussed the theoretical principals of internal combustion engines and the characteristics of a conventional timing system before revealing the shortcomings of the conventional timing system based on current demands for power, efficiency, and emissions reductions.

The second part of the project involved cam profile design, cam profile analysis, and reviews of existing variable valve timing system studies. The analysis allowed us to recognize the fundamental role in valve control, as well as the benefits from the variable valve timing / variable lift (VVT/VVL) system based on improved torque, power, and specific fuel consumption.

Next, The sizing work was then carried out for the main distribution elements: the timing belt, camshaft, and cam phaser. Each simulation would allow us to validate the mechanical feasibility of the system, define the important geometric parameters, and validate that the proposed solution would be compatible with the engine to be studied; the results provide a good foundation as we move on to the next step.

However, this thesis does not just go through a dimensional aspect. Work will continue with a numerical simulation of the camshaft behavior with a phaser and quantify the real advantages of the proposed system, particularly in terms of power, specific consumption, and pollutant emissions, as well as provide a comparison of the performance obtained against that of a conventional distribution system.

In conclusion, this study has demonstrated the importance and relevance of integrating a VVT system into an engine such as the K7M800. The design results obtained pave the way for numerical and experimental validation, which will complete this work and confirm the expected benefits in terms of energy efficiency and compliance with environmental standards.





## Bibliography

- [1] G.U.N.T. Gerätebau GmbH. Internal combustion engines – Basic principles. PDF document. G.U.N.T Gerätebau GmbH, n.d. [https://www.gunt.de/images/download/int\\_comb\\_engines\\_french.pdf](https://www.gunt.de/images/download/int_comb_engines_french.pdf)
- [2] Bouchard, Alain. The internal combustion engine has not said its last word. Online news article. La Presse, April 19, 2019. <https://www.lapresse.ca/auto/2019-04-19/le-moteur-a-combustion-interne-n-a-pas-dit-son-dernier-mot>
- [3] **Tohirova, Farangiz.** *System Identification and Automatic Control for the Cam Phasers of an Internal Combustion Engine.* Master's thesis. Department of Physics, Umeå University
- [4] Université de Tiaret. Internal combustion engine – Course material. PDF document. Faculty of Science and Technology, Université de Tiaret, n.d. <https://fsa.univ-tiaret.dz/doc/COURS/moteur.pdf>
- [5] Mat Foundry Group. What is a camshaft and how does it work? Online article. Mat Foundry Group, n.d. <https://www.matfoundrygroup.com/blog/what-is-a-camshaft-and-how-does-it-work>
- [6] Adobe Stock. Camshaft – 3D rendered illustration. Image. Adobe Stock, n.d. [https://stock.adobe.com/dz/search?k=camshaft&asset\\_id=269877129](https://stock.adobe.com/dz/search?k=camshaft&asset_id=269877129)
- [7] Elbachir Mohamed, Ammar and Bellaouri, Zouheir. Design of a synchronous hybrid transmission in an internal combustion engine. Master's thesis. Academic Master's Degree in Mechanical Engineering, specialization in Mechanical Construction, University of Mostaganem, 2023.

- [8] **Linquip**. *How valves work in an engine*. Online article. Linquip, n.d. <https://www.linquip.com/blog/how-valves-work-in-an-engine/>,
- [9] Linquip. *How valves work in an engine*. Online article. Linquip, n.d. <https://www.linquip.com/blog/how-valves-work-in-an-engine/>,
- [10] Guillaume Darding. (n.d.). *Technique : la distribution moteur*, from <https://www.guillaumedarding.fr/technique-la-distribution-moteur-3636107.html>
- [11] **Careco**. *Petrol engine – Dacia Sandero*. Online product page. Careco, n.d. <https://careco.fr/moteur-essence/9246-moteur-essence-dacia-sandero.html>,
- [12] Automaniac.org. *Renault 1.6 K7M 800 8V 85HP – 1598cc petrol engine specifications*. Online article. Automaniac, n.d. <https://www.automaniac.org/engine/renault/647/renault-1598cc-petrol-1.6-k7m-800-8v-85hp>
- [13] CarsArt.net. *Renault K7M engine – Specifications and details*. Online article. CarsArt, n.d. <https://www.carsart.net/en/engine/k7m>
- [14] Truck-Hyundai.ru. *Technical specifications of Renault engines – Renault K4M engine features*. Online article. Truck-Hyundai, n.d. <https://truck-hyundai.ru/en/tehniceskije-harakteristiki-dvigateli-reno-dvigatel-reno-k4m-osobennosti/>
- [15] General Motors. *GM 2-001936-EN-01 – Engine technical document*. PDF document. Scribd, n.d. <https://www.scribd.com/document/396784507/GM-2-001936-EN-01>
- [16] MyMotorList.com. *Renault K7M engine – Specifications and details*. Online article. MyMotorList, n.d. <https://mymotorlist.com/engines/renault/k7m/>
- [17] MotorReviewer.com. *Renault 1.6L K7M engine (8V)*. Online article. MotorReviewer, n.d. [https://www.motorreviewer.com/engine.php?engine\\_id=49](https://www.motorreviewer.com/engine.php?engine_id=49)

- [19] **Auto-Data.net**. *Dacia Sandero I Stepway 1.6 8V 84HP – Technical specifications*. Online data sheet. Auto-Data, n.d. <https://www.auto-data.net/fr/dacia-sandero-i-stepway-1.6-8v-84hp-17984>
- [20] Idolz.com. Variable valve timing. Online article. Idolz, n.d. <https://www.idolz.com/en/variable-valve-timing/>
- [21] ICICI Lombard. What is a VVT engine? Functions, working, advantages, and disadvantages. Online article. ICICI Lombard, n.d. <https://www.icicilombard.com/blogs/car-insurance/car/what-is-a-vvt-engine-functions-working-advantages-and-disadvantages>
- [22] Oryx Parts. Variable valve timing. Online article. Oryx Parts, December 20, 2022. <https://oryxparts.com/fr/blog/2022/12/20/distribution-variable/>
- [23] Ornikar. Variable valve timing in automobiles. Online educational article. Ornikar, n.d. <https://www.ornikar.com/code/cours/mecanique-vehicule/moteur/distribution-variable-automobiles>
- [24] L'Automobile Sportive. Engine timing systems (distribution). Online technical article. L'Automobile Sportive, n.d. <https://www.automobile-sportive.com/technique/distribution.php>,
- [25] EngineLabs. Video: Comparing variable valve lift and variable valve timing. Online article. EngineLabs, n.d. <https://www.enginelabs.com/news/video-comparing-variable-valve-lift-and-variable-valve-timing/>
- [26] AutoZine. Variable Valve Timing (VVT) – Part 5. Online technical article. AutoZine Technical School, n.d. [https://www.autozine.org/technical\\_school/engine/vvt\\_5.html](https://www.autozine.org/technical_school/engine/vvt_5.html)
- [27] Toyota USA. How VVT-i (Variable Valve Timing with intelligence) works. Video. YouTube, 9 February 2010. [https://www.youtube.com/watch?v=3vV\\_wcAybpc](https://www.youtube.com/watch?v=3vV_wcAybpc)
- [28] Nissan Motor Co., Ltd. Nissan world's first Variable Valve Event and Lift (VVEL) system. PDF technical presentation. Nissan Global, July 13, 2007. <https://www.nissan-global.com/EN/DOCUMENT/PDF/IREVENT/PRESEN/2007/070713VVEL-e.pdf>,

- [29] Natural Resources Canada. Variable valve timing (VVT) systems. PDF factsheet. Office of Energy Efficiency, Government of Canada, n.d. [https://natural-resources.canada.ca/sites/www.nrcan.gc.ca/files/oeef/pdf/transportation/fuel-efficient-technologies/autosmart\\_factsheet\\_15\\_e.pdf](https://natural-resources.canada.ca/sites/www.nrcan.gc.ca/files/oeef/pdf/transportation/fuel-efficient-technologies/autosmart_factsheet_15_e.pdf)
- [30] Arafin, Y. How variable valve timing improves gas engine efficiency. Online article. Yasir Arafin, n.d. <https://yasirarafin.com/how-variable-valve-timing-improves-gas-engine-efficiency/>
- [31] Huang, Y., Zhao, D., Liu, H., & Chang, J. Mode strategy for engine efficiency enhancement by variable valve timing and throttle control. Scientific article abstract. Journal of Energy Resources Technology, vol. 143, no. 6, 2021, Article ID 062307. <https://asmedigitalcollection.asme.org/energyresources/article-abstract/143/6/062307/1087805/>
- [32] TREA. Discrete variable valve lift engine systems and methods. Patent grant. TREA, n.d. <https://trea.com/information/discrete-variable-valve-lift-engine-systems-and-methods/patentgrant/bac6cac3-bd1f-4ca6-b40e-4c947e84366d>
- [33] **Number Analytics**. *Cams in modern mechanical mechanisms*. Online article. Number Analytics, n.d. <https://www.numberanalytics.com/blog/cams-in-modern-mechanical-mechanisms>
- [34] **MyIGETIT**. *Cam and follower mechanism*. Online technical article. MyIGETIT, n.d. <https://myigetit.com/tech/cam-and-follower-mechanism/>
- [35] **Techniques de l'Ingénieur**. *Cam mechanisms*. Online technical article. Techniques de l'Ingénieur, n.d. <https://www.techniques-ingenieur.fr/base-documentaire/mecanique-th7/transmission-de-puissance-mecanique-accouplement-embayage-freinage-42184210/mecanismes-de-transformation-de-mouvement-a-contact-local-b5910/mecanismes-a-cames-b5910niv10001.html>
- [36] Gates Corporation. 9257 synchronous rubber belt – Product page. Online catalog. Gates, n.d. <https://www.gates.com/kr/en/power-transmission/synchronous-belts/rubber-synchronous-belts.p.9257-000000-000000.html>

- [37] **MechLesson.** *Cam phaser: Definition, working, types & application.* Online technical article. MechLesson, n.d. <https://mechlesson.com/cam-phaser/>
- [38] **JAPH Powertrain.** *VVT (Variable Valve Timing) engine camshaft sprocket phaser.* Online product listing. Made-in-China, n.d. <https://japhpowertrain.en.made-in-china.com/product/OaLRBtfvvEhG/China-Vvt-Variable-Valve-Timing-Engine-Camshaft-Sprocket-Phaser.html>
- [39] **Hot Rod.** *Variable valve timing advantages.* Online article. Hot Rod, December 2012. <https://www.hotrod.com/articles/1212phr-variable-valve-timing-advantages>
- [40] Dassault Systèmes. *SolidWorks 2023.* Software. <https://www.solidworks.com>
- [41] ToyotaNation Forum. *Airbag light with no fault codes.* Online forum discussion. ToyotaNation, n.d. <https://www.toyotanation.com/threads/airbag-light-with-no-fault-codes.1788611/>
- [42] *Quantitative study on influence factors of power performance of variable valve timing (VVT) engines and correction of its governing equation* — Z. Yuan et al., 2018. Étude qui quantifie l'effet de divers paramètres du VVT sur la performance-moteur.
- [43] **Conquer Driving.** *How to drive a manual car – Driving lesson with clutch advice.* Video. YouTube, (n.d.). <https://www.youtube.com/watch?v=VIVaqt4VhKc&t=4s>
- [44] **Ansys, Inc.** *Official website.* Company web page. Ansys, n.d. <https://www.ansys.com>