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The Analysis of Internal Combustion Engine Concept: The Five-Stroke Cycle as an Innovative Advancement in the Automotive Sector

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Abstract

In this paper, a new design for the Internal Combustion Engine (ICE) is presented, featuring characteristics that are superior to its predecessors and have the potential to advance technology in the field. Technically, the concept involves adding an additional step to the classical four-stroke cycle in order to extract more work. The design incorporates an ICE with three cylinders: two high-pressure cylinders and a third low-pressure cylinder. The high-temperature exhaust gases from the four-stroke engine contain energy that can be further utilized to extract additional work, improving overall efficiency and reducing emission temperatures. Through this extraction concept, the additional work produced by the new design aims at enhancing efficiency and reducing structural weight. It was found that adding an extra step to the four-stroke ICE can lead to an increased expansion ratio and thermal efficiency. This is made possible by the extended expansion performed by the low-pressure cylinder, which has a larger volume compared to the two high-pressure cylinders. The extended stroke helps generating greater torque and output power while consuming less fuel mixture, thus improving the overall efficiency.

Keywords : ICE, Five-Stroke Engine Efficiency, Thermodynamics, Lower Emissions, Higher Output Power, and Lighter Structure

INTRODUCTION

Energy is a primary necessity in a production facility, where the energy expenditure occupies one of the top three positions in the monthly budget. Therefore, it is crucial to closely monitor its fluctuations due to the significant impact on the efficiency of the production facility. The price changes of energy raw materials in Indonesia have a highly sensitive reaction among industry players, considering that the energy expenditure component in the production process is substantial. As discussed above and as a point of focus, the procurement of fuel oil is a significant cost component in the operation of passenger or freight transportation services. Additionally, fuel oil is a valuable commodity, making it a highly sensitive issue with multiple stakeholders involved. Fuel oil, derived from fossil energy sources, is a non-renewable energy resource. Eventually, this energy source will be depleted, necessitating its use to be as efficient as possible.

The significant cost of fuel in the transportation of goods and people, combined with the large quantities of fuel burned, also contributes to considerable environmental damage. In this paper, we will review a new concept in the Internal Combustion Engine (ICE) that offers better features compared to its predecessors and represents an advancement in engine technology—the Five-Stroke Internal Combustion Engine. Due to the broad scope of the topic and time limitations, the research team has decided to focus the discussion on the Five-Stroke Cycle Internal Combustion Engine as applied to Otto Cycle Engines (spark-ignition engines) in relation to the following issues:

1. The Design, Structure, and Operating Principle of the Five-Stroke Internal Combustion Engine Concept.
2. Comparison of Characteristics, Advantages, and Disadvantages of the Five-Stroke Internal Combustion Engine Concept.

The objectives of this study are as follows:

a) To understand and analyze the design, structure, and operating principles of the Five-Stroke Cycle Internal Combustion Engine concept.
b) To compare the characteristics, advantages, and disadvantages of the Five-Stroke Internal Combustion Engine concept in relation to conventional internal combustion engines with previously established cycles.

METHOD

The research method used by the research team in this study is the qualitative descriptive method. The study was conducted at the Higher School of Shipping, Jakarta. Data collection techniques included indirect interviews (via email), literature review, and documentation. The data analysis technique employed was qualitative descriptive analysis.

RESULTS AND DISCUSSION

Results

Design, Structure, and Operating Principles of the Five-Stroke Cycle Internal Combustion Engine Concept

The engine consists of three cylinders mounted on a single crankshaft that rotates with a specified configuration, where precise timing is required to move the cylinders during the different strokes at the appropriate moments.

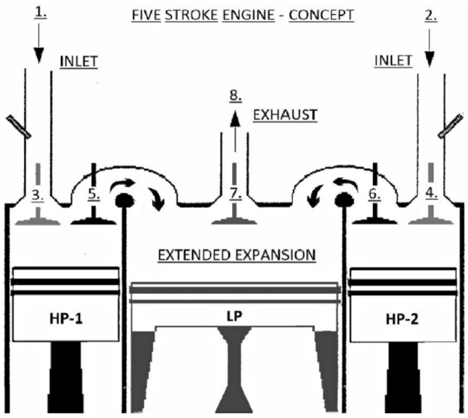

Figure 1. Cylinder Configuration in the Five-Stroke Engine Block

As shown in Figures 1 and 2, the engine block features a three-cylinder configuration, consisting of two high-pressure cylinders that perform the main work and have a smaller volume compared to the low-pressure cylinder, which has almost twice the volume of the high-pressure cylinders. The low-pressure cylinder is positioned between the two high-pressure cylinders, working in coordination with them and aiding in providing additional energy through the extended expansion stroke, thereby improving the overall efficiency of the engine.

Figure 2. External View of the Five-Stroke Engine Block

Figure 2 shows the external view of the Five-Stroke Engine block, which is made from an alloy produced through a casting process. It features space for three cylinders mounted within its compartment. Two cylinders with smaller diameters are positioned at both ends, while a larger diameter cylinder is placed in the center. Figure 3 illustrates various essential components of the Five-Stroke Engine assembly, including the cylinders (HP-1, HP-2, and LP), piston rods, valves, camshaft, crankshaft, and others, along with the configuration of the crank cheeks at each degree. It is clearly shown that the rotation of the crankshaft in the required direction ultimately facilitates the proper movement of the valves and ensures the correct operation of the cylinders.

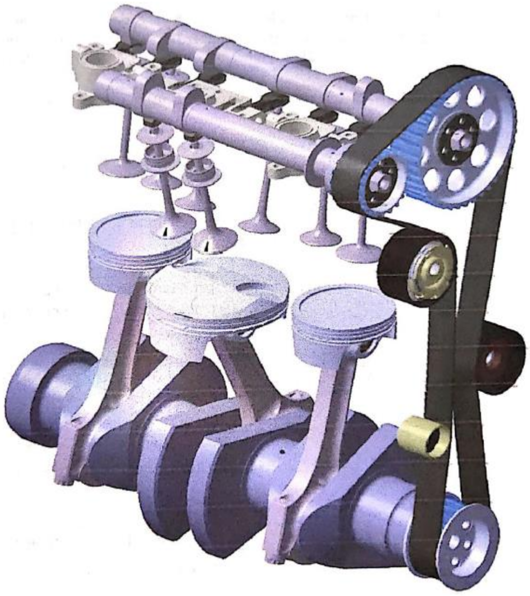

Figure 3. Internal View of the Main Components of the Five-Stroke Engine

From the design and structure of the Five-Stroke Internal Combustion Engine concept outlined previously, it naturally leads to a change in the power calculation generated by this engine concept. The mathematical formula for calculating the power output of the Five-Stroke Internal Combustion Engine concept consists of the following:

a) Formula for Calculating High-Pressure Cylinder (HP-Cylinder) Power

The power calculation for the high-pressure cylinder is essentially the same as the formula used for calculating the power of a four-stroke engine, which is:

$$P_{i(HP_{cyl})} = {}^{\pi}/_{4} . D_{(HP)^2} . S . {}^{n}/_{a} . Z_{(HP)} P_{i(HP)} . 100 (KW)$$

b) Formula for Calculating Low-Pressure Cylinder (LP-Cylinder) Power

The power calculation for the low-pressure cylinder is essentially the same as the formula used for calculating the power of a two-stroke engine, which is:

$$P_{i(LP_{cyl})} = {}^{\pi}/_{4} . D_{(LP)^2} . S . {}^{n}/_{a} . Z_{(LP)} P_{i(LP)} . 100 (KW)$$

c) Formula for Calculating the Total Power of the New Five-Stroke Internal Combustion Engine Concept

The formula for calculating the total power of the Five-Stroke Internal Combustion Engine concept is as follows:

$$P_{i(total)} = P_{i(HP_{cyl})} + P_{i(LP_{cyl})}$$

Description:

$P_{i(total)}$ = Total indicator power of the five-stroke engine cycle (KW)

$P_{i(HPcyl)}$ = Indicator power of the high-pressure cylinder (KW)

$P_{i(LPcyl)}$ = Indicator power of the low-pressure cylinder (KW)

$D_{(HP)}$ = Diameter of the high-pressure cylinder (meters)

$D_{(LP)}$ = Diameter of the low-pressure cylinder (meters)

S = Piston stroke (meters)

n = Crankshaft speed (RPS = revolutions per second)

a = Crankshaft rotation to work stroke ratio

a = 1 (for 2-stroke) dan a = 2 (for 4-stroke)

Z_{HP} = Number of high-pressure cylinders

Z_{LP} = Number of low-pressure cylinders

$P_{i(HP)}$ = Average indicator pressure of the high-pressure cylinder (bar)

$P_{i(LP)}$ = Average indicator pressure of the low-pressure cylinder (bar)

d) Operating Principle of the Five-Stroke Cycle Internal Combustion Engine Concept

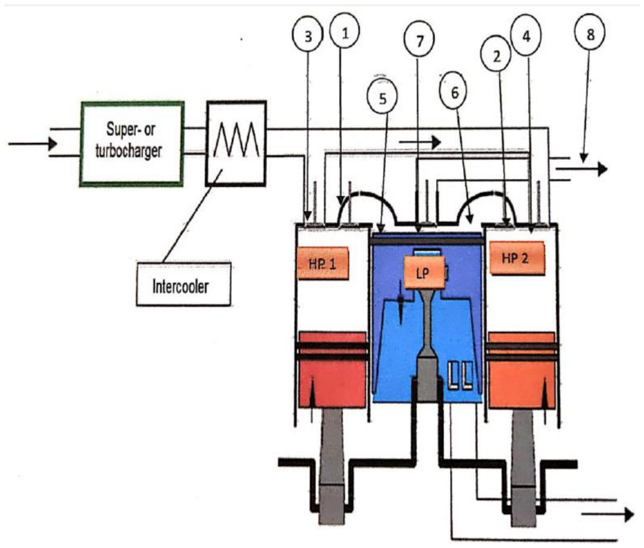

Figure 4. Sketch of the Five-Stroke Engine Concept

Description:

HP-1 : High-Pressure Cylinder (1)

HP-2 : High-Pressure Cylinder (2)

LP : Low-Pressure Cylinder

1&2 : Exhaust Valve for High-Pressure Cylinder

3 & 4 : Intake Port for Low-Pressure Cylinder

5 & 6 : Intake Valve for High-Pressure Cylinder

7 : Exhaust Valve for Low-Pressure Cylinder

8 : Exhaust Gas Port

Table 1. Working Process of Each Cylinder in the Five-Stroke Engine

Step Sequence	High-Pressure Cylinder (HP-1) Working Process	Low-Pressure Cylinder (LP-Cyl) Working Process	High-Pressure Cylinder (HP-2) Working Process	Step Sequence
Ke-1	Charging	Exhaust to atmosphere	Expansion	
Ke-2	Compression	Extended Expansion	Extended Expansion (to LP-cyl)	
Ke-3	Expansion	Exhaust to atmosphere	Charging	Ke-1
Ke-4	Extended Expansion (to LP-cyl)	4. Extended Expansion	Compression	Ke-2
Ke-5	Charging	5. Exhaust to atmosphere	Expansion	Ke-3
		4. Extended Expansion	Extended Expansion (to LP-cyl)	Ke-4
		5. Exhaust to atmosphere	Charging	Ke-5

Discussion

Comparison of the Characteristics, Advantages, and Disadvantages of the Five-Stroke Internal Combustion Engine Concept

Thermodynamic Cycle of the Five-Stroke Otto Engine.

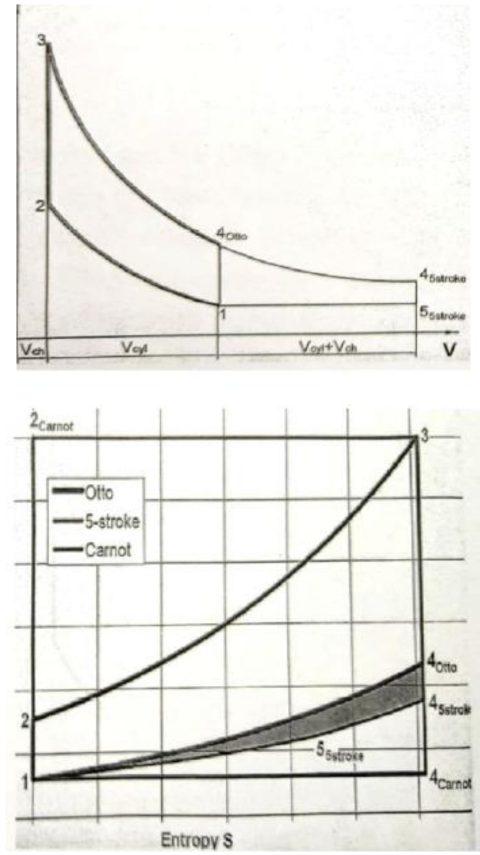

Figure 5. (p-v) and (t-s) Diagrams of the Five-Stroke Otto Engine Cycle

Description:

5 – 1 : Intake process (isobaric)

1 – 2 : Compression process (adiabatic)

2 – 3 : Combustion process (isochoric)

3 – 4 : Expansion process (adiabatic)

4 – 4* : Extended expansion process (adiabatic)

4* – 5 : Exhaust process (isochoric)

Below is Table 2, comparing the characteristics of the Otto (Gasoline) Engine at various operating cycles.

Table 2. Comparison of Characteristics of Each Cycle Type (in Otto Cycle Engines)

No	Step (Process)	Siklus Kerja Mesin		
		2-Stroke	4-Stroke	5-Stroke
1	Intake / Scavenging	New air intake into the cylinder requires	New air intake into the cylinder is more optimal	New air intake into the cylinder is more optimal

		auxiliary equipment: blower, scavenging pump, turbocharger	(positive pressure occurs)	(positive pressure occurs)
2	Compr ession	With a high compression/ expansion ratio, the risk of 'knocking' is higher, so it is equipped with anti-knocking control protection	With a high compression/ expansion ratio, the risk of 'knocking' is higher, so it is equipped with anti-knocking control protection	Two-stage compression/ expansion occurs in both HP and LP cylinders, reducing the risk of knocking
3	Expans ion / Power Stroke	Only one power stroke occurs per full rotation	Only one power stroke occurs per two full rotations	Two-stage compression/ expansion occurs in both HP and LP cylinders, resulting in greater power output due to the additional power generated in the LP cylinder
4	Exhaus t	The exhaust process is not fully efficient. The heat content of the exhaust gases leaving the cylinder is still high	The heat content of the exhaust gases leaving the cylinder is still high	The heat content of the exhaust gases leaving the cylinder is lower
Summary		a. The power output is greater	a. The power output is lower	a. The power generated is higher
		b. Fuel consumption is higher	b. Fuel consumption is lower	b. Fuel consumption is lower
		c. Exhaust emissions are higher	c. Exhaust emissions are higher	c. Exhaust emissions are lower
		d. Less environmentally friendly	d. Less environmentally friendly	d. More environmentally friendly

Sources: Gerhard Schmitz, 5-Stroke Engine Concept

1. Advantages
   a) Additional Power Output: The system gains additional power output due to the extended expansion process in the Low Pressure (LP) cylinder, utilizing exhaust gases from the High Pressure (HP) cylinder expansion.
   b) Reduced Components and Fuel Consumption: To generate the same power as a conventional combustion engine, the five-stroke engine requires fewer components and less fuel consumption.
   c) Improved Thermal Efficiency: The engine increases thermal efficiency by minimizing heat losses, particularly the heat carried away by the exhaust gases discharged from the chimney.
   d) Environmental Friendliness: The system is more environmentally friendly as it indirectly reduces exhaust emissions released into the atmosphere.
2. Disadvantages
   a) Under Research and Development: The five-stroke engine is still in the research and development phase by various manufacturers, with most of them keeping their research results confidential.
   b) Prototypes Based on Otto Cycle: Current prototypes of the five-stroke engine are still based on the gasoline engine (Otto cycle) and have not yet been tested with diesel engine prototypes.

CONCLUSION

The new concept of the Five-Stroke Internal Combustion Engine represents a groundbreaking development by mechanical experts, building upon the previous advancements in the Four-Stroke and Two-Stroke engine cycles. The new concept offers numerous advantages compared to its drawbacks. This innovative design of the Five-Stroke Internal Combustion Engine is expected to become one of the leading engine technologies in the future, offering higher power output, improved fuel efficiency, and greater environmental friendliness.

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