International Scientific Journal of Engineering and Management (ISJEM) ISSN: 2583-6129
Volume: 04 Issue: 04 | April – 2025 DOI: 10.55041/ISJEM02937
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata

DEMONSTRATION OF VARIABLE DISPLACEMENT PISTON PUMP

SANJANA CHAUDHARI[1], SANIKA MODAK[2], SNEHAL PAWAR[3], IFFAT KALLURU[4], RUSHIKESH KAPSE[5], AJIT DHANWADE[6]

[12345]*Pune Institute of Aviation Technology, affiliated to Savitribai Phule Pune University, Pune, India*

---***---

Keywords: *swash plate, oscillations, piston pumps, variable displacement mechanism*

1. ABSTRACT

Variable displacement piston pumps are crucial in modern aviation hydraulic systems, providing precise and efficient fluid power management. These pumps adjust their displacement according to system demands, optimizing energy consumption and reducing heat generation. They operate using an axial or radial piston mechanism, with a swash plate or cam arrangement controlling the stroke length of the pistons. This adjustability allows for improved performance, reduced weight, and enhanced reliability compared to fixed displacement pumps.

These pumps are also essential for hydraulic actuation in flight control systems, landing gear, braking, and thrust reversers. Their ability to maintain consistent pressure while varying flow rates contributes to operational efficiency and fuel savings.

2. INTRODUCTION

A variable displacement piston pump is a type of hydraulic pump capable of converting mechanical energy into hydraulic energy, with the added functionality of adjusting the volume of fluid displaced per revolution of the pump's input shaft during operation. This ability to regulate displacement allows for improved control of hydraulic output in response to system demands, contributing to greater overall efficiency and flexibility. Notably, many variable displacement pumps are designed to be reversible, enabling them to operate hydraulic motors by converting hydraulic energy back into mechanical energy when required. One of the most common implementations of this technology in aviation applications is the axial piston pump, which offers high efficiency, compact design, and the ability to operate under high-pressure conditions, making it well-suited for aircraft hydraulic systems.

International Scientific Journal of Engineering and Management (ISJEM) ISSN: 2583-6129
Volume: 04 Issue: 04 | April – 2025 DOI: 10.55041/ISJEM02937
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata

These pumps operate by varying the stroke length of their pistons, controlled via a swashplate mechanism or electronic/hydraulic feedback systems. A variable displacement piston pump adjusts its output flow rate based on system demand, making it more energy-efficient than fixed displacement pumps. This adaptability is particularly advantageous in aviation, where weight, efficiency, and reliability are paramount. These pumps regulate hydraulic pressure dynamically, reducing unnecessary power consumption and minimizing heat generation, which can be crucial for aircraft operation at varying altitudes and environmental conditions.

This review paper aims to provide a comprehensive analysis of variable displacement piston pumps in aviation, covering their working principle, design considerations, performance characteristics, advantages over fixed displacement pumps, and future trends.

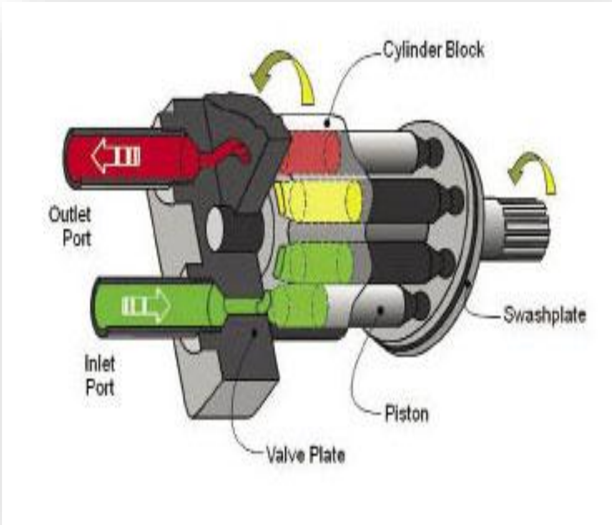
3. METHODOLOGY

The methodology employed in variable displacement piston pumps is a regulated control system.

The variable displacement piston pump uses a controlled mechanism to adjust the displacement of the piston or the angle of the swashplate. This mechanism may include a hydraulic feedback system, electronic controls, or manual adjustments.

A typical variable displacement piston pump consists of a control orifice, a compensator spring, relief holes, a spider, a drive cam, a piston sleeve, and a compensator piston.

In this project, we have tried to reduce the complexity of the construction parts, and also we have made a very pocket-friendly but very informative demonstration of the variable displacement piston pump. In this model, we are using plastic cylinders, steel shafts, a sphere made of metal, plates made of metal, a handle, a mockup plate for assembly of the model, also a rod.



3.1 Design

This variable displacement piston pump stimulates several pistons in cylinders arranged parallel to each other and rotating around a central shaft. In a variable displacement piston pump, the swashplate mechanism plays a critical role in regulating fluid flow. The swashplate, inclined relative to the drive shaft, is mechanically linked to a series of pistons arranged in a circular pattern within a cylinder block. As the drive shaft rotates, the pistons reciprocate due to the varying displacement imposed by the swashplate’s angle. This reciprocating motion enables the pistons to draw fluid in and expel it through the intake discharge port, which are alternately connected via a rotary valve. By alternating the angle of the swashplate, the piston stroke and consequently the pump’s output can be continuously adjusted. When the swashplate is set perpendicular to the axis of rotation, piston movement ceases, halting the fluid flow. Increasing the tilt angle results in a proportional increase in flow rate. Advanced designs permit bidirectional adjustment of the swashplate from the neutral position, allowing for flow reversal without changing the rotational direction of the pump.

Figure 1. *Pump structure diagram*

International Scientific Journal of Engineering and Management (ISJEM) ISSN: 2583-6129
Volume: 04 Issue: 04 | April – 2025 DOI: 10.55041/ISJEM02937
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata

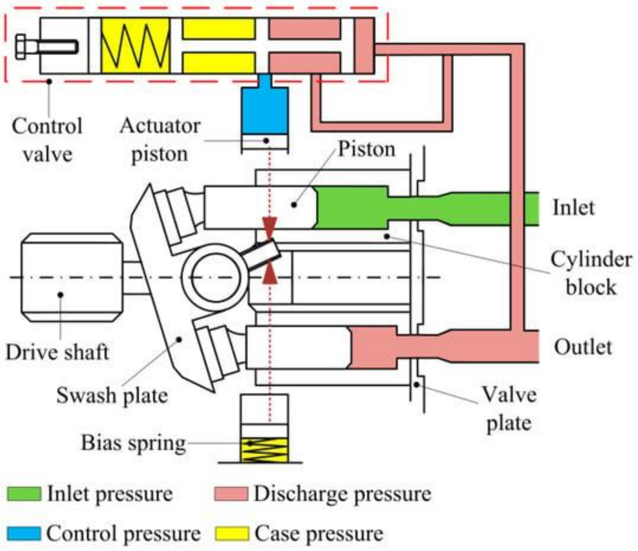


Figure 1 presents the basic principle of the variable displacement piston pump.

4. IMPLEMENTATION PLAN

- HANDLE AND MOVABLE SHAFT: As we rotate the handle manually, the shaft will move as well.

- PISTON AND CYLINDER BLOCK: The pump consists of a series of pistons arranged in a circular pattern within a rotating cylinder block. The pistons are connected to a swashplate, which is angled to control the piston movement.

- SWASHPLATE: The angle of the swash plate determines the stroke length of the pistons. When the swashplate is tilted, the piston moves IN and OUT of its cylinders as the block rotates. This motion creates suction and discharge, drawing fluid into the pump and then pushing it out.

- VARIABLE DISPLACEMENT CONTROL: By alternating the angle of the swashplate, the displacement of the pump can be adjusted. A steeper angle increases piston travel, resulting in higher fluid displacement and thus a higher flow rate. Reducing the swashplate angle decreases the displacement, lowering the flow rate.

- CONTROL MECHANISM: The adjustment of the swashplate angle is typically controlled by a hydraulic actuator or mechanical linkage, often governed by feedback from the system's pressure or flow demands. In systems requiring precise control, electronic feedback loops may be employed.

- OUTPUT CONTROL: By varying the piston displacement, the pump can adapt to the system's needs, either increasing flow when demand is high or reducing it when lower pressure is required, enhancing efficiency and reducing energy consumption.

5. WORKING

5.1 WORKING OF COMPONENTS

The Variable Displacement Piston pump relies on several interconnected components to function effectively.

- **The Piston Assembly** is the core element of the variable displacement piston pump. It consists of pistons that move within cylinders arranged around a central axis. The pistons are typically connected to a swashplate or other similar mechanism.
- **The Swashplate** is a critical component that determines the displacement of the pump. It is an adjustable plate that changes the angle at which the pistons are positioned, thereby controlling the volume of hydraulic fluid displaced per cycle.
- **The control mechanism (Hydraulic or electronic)** is responsible for adjusting the angle of the swashplate based on the system's needs for hydraulic pressure and flow. This is typically done through either a hydraulic servo mechanism or, in modern systems, an electronic controller. A potentiometer varies the voltage in a circuit by regulating the resistance. It is used to vary the RPM of the respective motor used.
- **The drive shaft** is the component that connects the pump to the engine or another power source in the aircraft. It provides the rotational energy necessary to operate the pump.
- **The reservoir** stores hydraulic fluid, ensuring that there is a sufficient supply for the pump and other components in the hydraulic system.
- **The pump housing** encloses all the moving components and provides a sealed environment that ensures the hydraulic fluid remains contained and that the pressure is maintained within the system.

ISSN: 2583-6129
DOI: 10.55041/ISJEM02937

- **Bearings** reduce friction between rotating parts, while seals prevent hydraulic fluid from leaking out of the pump.

7. BASIC WORKING OF THE FULL SYSTEM IN **STEPS**

1. **Power Source Activation**:

- The system starts when the drive shaft (connected to the aircraft engine or auxiliary power unit) begins to rotate.
- The rotational energy from the drive shaft powers the pump, initiating the movement of internal components.

2. **Piston Movement**:

- Inside the pump, pistons are arranged in cylinders around a central axis.
- As the drive shaft turns, it rotates a swashplate (or similar mechanism) that is linked to the pistons.
- The swashplate's angle determines how far the pistons travel in their cylinders. The greater the angle, the larger the displacement of the piston (more fluid is pumped).

3. **Swashplate Adjustment**:

- The **angle of the swashplate** is adjusted based on the **demand for hydraulic power**.
- If more fluid is needed by the system (e.g., for flight control, landing gear, or other hydraulic systems), the swashplate angle increases, causing the pistons to displace more fluid.
- Conversely, if the system requires less fluid, the swashplate angle decreases, reducing the displacement per cycle.

4. **Fluid Intake**:

- As the pistons move within their cylinders, they draw **hydraulic fluid** from the **reservoir** into the pump. The fluid enters through intake ports and is displaced under pressure as the pistons move.

5. **Fluid Displacement and Pressurization**:

- When the pistons move inward (due to the swashplate's angle), they force the **hydraulic fluid** out of the cylinders and into the hydraulic system under pressure.
- The pump creates **pressurized fluid** that is directed toward various components of the aircraft's hydraulic system.

6. **Flow Control and Pressure Regulation**:

- A **flow control valve** regulates the amount of fluid flowing into the system, ensuring that only the required amount of hydraulic power is delivered.
- If the pressure in the system exceeds safe limits, a **pressure relief valve** will open to bypass the excess fluid and prevent damage.

7. **Fluid Distribution**:

- The pressurized fluid is then distributed through the **hydraulic lines** to power various systems on the aircraft, such as flight controls, landing gear, brakes, etc.

8. **System Feedback and Adjustment**:

- The **control mechanism** continuously monitors the system's demands (e.g., pressure or flow) through sensors. Based on the feedback received, it dynamically adjusts the **swashplate angle** to regulate the fluid flow, either increasing or decreasing it as required to maintain the fluid flow.
- If there is an increase in hydraulic demand, the control mechanism will adjust the swashplate angle to displace more fluid. If demand decreases, the angle is reduced to lower the displacement.

9. **Returning Fluid**:

- After the hydraulic fluid is used by various systems, it returns to the **reservoir** for cooling and filtration. The fluid is then ready to be drawn into the pump again for the next cycle.

10. **Shutdown**:

- When the pump is no longer needed, the drive shaft stops rotating, and the pistons cease moving.

- The **control mechanism** ensures that the swashplate is set to a neutral position, preventing further fluid displacement.

6. EFFECTIVENESS

A variable displacement piston pump is highly effective in applications requiring adaptable fluid power, offering significant energy efficiency and system flexibility. Unlike fixed displacement pumps, which deliver a constant flow regardless of demand, variable displacement pumps adjust the flow rate and pressure based on system requirements. This adaptability minimizes energy wastage, reduces heat generation, and improves system performance. The pump's ability to match output to load conditions not only enhances operational efficiency but also extends the lifespan of hydraulic components by reducing wear and tear. As a result, variable displacement piston pumps are widely used in industrial, mobile, and aerospace hydraulic systems where efficiency, control, and reliability are critical.

7. LIMITATIONS

Variable displacement piston pumps are more complex than fixed displacement pumps due to the need for control mechanisms (such as servo valves or electronic controls) to vary the displacement. This complexity can make them harder to design, operate, and maintain. The complexity can also result in higher maintenance requirements and also in expenses. If the displacement cannot adjust precisely to the load, it can lead to energy wastage or excessive heat generation in the hydraulic system.

8. EXPECTED RESULTS

The expected result of a variable displacement piston pump is improved efficiency, reduced energy consumption, and a longer lifespan for hydraulic systems. This is because a variable displacement piston pump can adjust the flow of fluid to match the needs of the system in real time.

9. FUTURE SCOPE

The **future scope of Variable Displacement Piston Pumps (VDPPs) in aviation** is promising due to advancements in aerospace technology, fuel efficiency requirements, and sustainability goals.

1. Improved Fuel Efficiency and Performance

- VDPPs allow aircraft hydraulic systems to **adjust flow rates dynamically**, reducing unnecessary energy loss.
- More **efficient power management** leads to lower fuel consumption, benefiting airlines aiming for reduced operational costs.

2. Integration with More Electric Aircraft (MEA) Concepts

- Future aircraft are moving toward **More Electric Aircraft (MEA)** and **Hybrid-Electric Propulsion Systems**.
- VDPPs can complement **electro-hydrostatic actuators (EHAs)** for better efficiency and redundancy.

3. Advanced Materials and Manufacturing

- The use of **lightweight composites and 3D-printed components** will make VDPPs more durable and lightweight.
- **Smart sensors and AI-driven diagnostics** will enable predictive maintenance, reducing failures and downtime.

4. Higher System Reliability and Safety

Future aviation demands **fail-safe hydraulic systems** with real-time monitoring.

- AI-driven **adaptive control** will allow pumps to self-adjust for optimal performance.

5. Role in Sustainable Aviation and Green Technologies

- **Hydrogen-powered and electric aircraft** still need high-efficiency hydraulic systems for landing gear, flaps, and control surfaces.
- VDPPs can be optimized for use in **biofuel-based or hybrid-electric propulsion systems**, aligning with **carbon-neutral goals**.

6. Unmanned Aerial Vehicle (UAV) and Urban Air Mobility (UAM).

- **Autonomous drones and air taxis** require compact and efficient hydraulic solutions, making VDPPs essential.
- These pumps could be **miniaturized and integrated with AI-based flight control systems**.

10. CONCLUSION

The variable displacement piston pump can change the inlet and outlet ports of the flow by changing the swashplate angle of the pump. The variable displacement piston pump also improves energy efficiency, longer lifespan, improves systems design flexibility, also reduces maintenance and operating tasks.

ISSN: 2583-6129
DOI: 10.55041/ISJEM02937

11. REFERENCE

- Easa 11a – Turbine Aeroplane Structures and Systems.
- Aircraft Hydraulic Systems – By Dale Crane.
- Airframe and powerplant mechanics – 15a
- AMR
- Jeppesen
- Displacement control in variable displacement axial piston swashplate type pumps
- https://www.mdpi.com/2076-3417/8/5/658 "Investigation into the effects of the variable displacement mechanisms on swash plate oscillations in high-speed piston pumps" - Xu Fang, Xiaoping Ouyang, and Huayong Yang, 6 March 2018. https://www.researchgate.net/publication/317345576_Displacement_Control_In_Variable_Displacement_Axial_Piston_Swashplate_Type_Pumps