Case Study Cyber Physical Production Systems using AM-SS(2023)
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Axial Piston Pump

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1 Abstract

Dieser technische Bericht gibt einen detaillierten Überblick über Axialkolbenpumpen, einschließlich ihrer Funktionen, Konstruktion, Stärken, Schwächen und alternativen Lösungen. Diese Pumpen sind in verschiedenen Anwendungen weit verbreitet, von der Automobilindustrie bis zur Schwerindustrie. Der Bericht erörtert die Konstruktion von Axialkolbenpumpen und ihre Funktionsweise, wobei der Schwerpunkt auf der Rolle von Steuerplatten und Zylindern liegt. Neben den Vorteilen dieser Pumpen - wie Effizienz, Druckkapazität, kompakte Größe und Langlebigkeit - werden auch ihre Nachteile wie hohe Kosten, Geräuschpegel, Komplexität und Leckageprobleme hervorgehoben. Der Bericht stellt auch alternative Lösungen wie Radialkolbenpumpen, Zahnraddosierpumpen, Flügelzellenpumpen und Membranpumpen vor, die für bestimmte Anwendungen anstelle von Axialkolbenpumpen in Frage kommen können. Insgesamt bietet dieser Bericht einen umfassenden Überblick über Axialkolbenpumpen und ihre Bedeutung in industriellen Anwendungen.

This report gives an overview of axial piston pumps, covering their structure, functionali-ty, and uses. Axial piston pumps are classified as positive displacement pumps that pro-duce high pressure and can be found in hydraulic systems such as heavy machinery and construction equipment. The report examines the strengths and weaknesses of axial pis-ton pumps while also suggesting alternative options like radial piston pumps, gear pumps, vane pumps, and diaphragm pumps. Additionally, the paper explores the impact of recent advancements in additive manufacturing on axial piston pump production and design. Ultimately, the report concludes by summarizing its key findings and offering rec-ommendations for future research and development in this area.

2 Introduction

Positive displacement pumps known as piston pumps fall into three basic categories: axial piston pumps with swash plates, bend axis piston pumps, and radial piston pumps. Swash plate axial piston pumps, also known as axial piston pumps, are the type of pump being discussed in this chapter. It features a housing that is typically referred to as a cylindrical block, rotor, or barrel, and an odd number of pistons placed in a circular arrangement within the housing. A central shaft that is positioned to be in line with the pistons that are pumping causes the cylinder block to revolve along its axis of symmetry. The two sub-categories of axial piston pumps are fixed displacement and variable displacement. The piston's stroke cannot be changed in

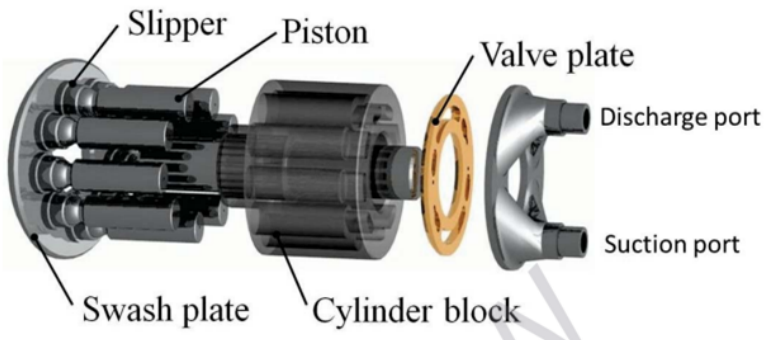

Figure 1: Axial Piston Pump

fixed displacement pumps; however, it may be changed in variable displacement pumps. Figure 1.1 displays the various components of an axial piston pump with variable dis-placement in cross-section. In fact, the understanding of fluid behavior in all pump mov-ing parts is directly related to the total pump efficiency and performance, making the study of axial piston pump moving parts crucial 1 to evaluating volumetric, mechanical, and hydraulic efficiencies.

3 Type of Piston Pumps

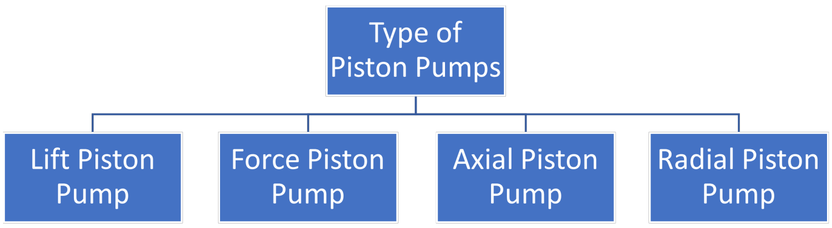

Figure 2: Tpe of axial piston pumps

4 Construction of Axial Piston Pumps

4.1 Piston Pump Parts

This pump's structure is a little intricate, and there aren't many spaces between the oper-ating sections. It guarantees a steady discharge at high pressure. There are several minor distinctions between this variety and other ones. It is crucial to carefully inspect each of its parts as a result. Let's examine the parts of a typical straight axis piston pump.

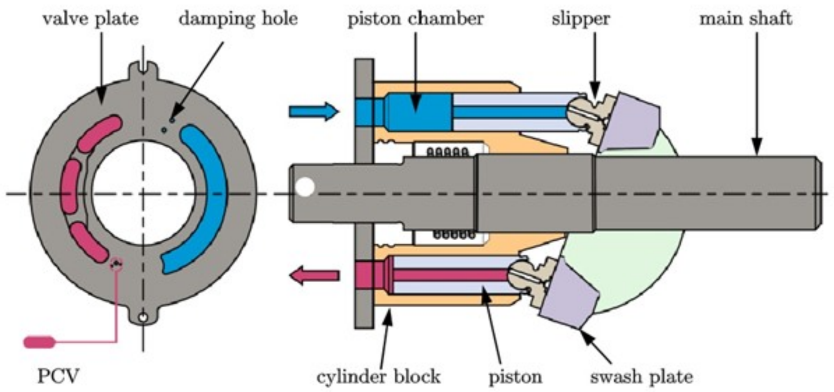

Figure 3: Axial Piston Pump Components

he housing is constructed from a long-lasting, rust-resistant material, often an alloy of steel. This area serves as storage for the valve plate, piston assembly, cylinder block, swashplate, shoe plate, and driven shaft.

4.2 Cylinder Block

The axial piston pump relies heavily on the cylinder block, which serves as the housing for its pistons. Typically composed of either cast iron or aluminum, this component features a sequence of radial bores that extend through its length. The exact quantity of these bores tends to fluctuate based on the overall size and capability of the pump. [6] The main purpose of the cylinder block is to offer a sturdy framework that can endure the force created by the pumped fluid while also supporting the pistons. The bores within this block are accurately crafted to provide a smooth surface for the seamless movement of pistons. Proper size and shape of these bores are essential in obtaining optimal flow rate and pressure of the pumped fluid. [4] The pump's cylinder block can be removed easily for repair or maintenance purposes. The block is usu-ally secured to the housing of the pump with bolts and gaskets to guarantee a secure seal between the two parts. The block often comes with built-in mounting points that enable easy installation and re-moval from the pump assembly.

4.3 Swash plate

A key element in an axial piston pump that manages the piston stroke is known as the swash plate. It is usually composed of steel or aluminum and is flat, placed at an angle to the drive shaft.The plate that causes the pistons to move back and forth within their bores is positioned on the opposite side of the cylinder block from the drive shaft and stays in touch with the piston heads. The stroke of the pistons can be controlled by adjusting the swash plate angle. A longer piston stroke can be achieved with a steeper angle, and a shorter one with a shallower angle. The fluid pressure and flow rate delivered by the pump can be adjusted by changing the swash plate angle. A shaft is usually used to connect the swash plate to an adjusting mechanism. This mechanism can be operated manually or electronically, depending on the need for precise adjustment of the angle of the swash plate. The swash plate is an essential part of the axial piston pump, which manages the piston's motion and de-termines the fluid's flow rate and pressure. Altering its angle can modify the piston stroke, and it is usu-ally fixed on a shaft that links to an adjustment mechanism for accurate handling. [7] [8]

4.4 Piston

An axial piston pump requires pistons to produce the suction and discharge process, making them a vital component. The quantity of pistons included in an axial piston pump can differ based on its size and capacity.Pistons are placed radially in the cylinder block and are usually constructed from steel or a comparable material that has high strength. These cylindrical pistons move within their bores as a result of the rotation of the drive shaft. [9] The swash plate can be angled to change the piston stroke, affecting the fluid flow rate and pressure delivered by the pump. The pistons' heads are touching the swash plate.The fluid is drawn into the pump through the suction port and then discharged through the outlet port due to the reciprocating motion created by the pistons. Achieving the desired flow rate and pressure of the pumped fluid de-pends on how well-designed the pistons and cylinder block are. The pump's piston system is engineered for effortless replacement in case of wear or damage. By de-taching the piston heads from the body, they can be readily exchanged with new ones to revive the pump's efficiency.The pistons play a vital role in the functioning of an axial piston pump by facilitating the suction and discharge process. They are constructed using durable materials and engineered to re-ciprocate within their bores while the drive shaft rotates, thereby generating the required movement to propel the fluid. [6] Drive shafts A vital part of an axial piston pump is the drive shaft, which transfers energy from an outside power supply to the pump. It is typically constructed from robust steel and engineered to endure significant levels of pressure and tension. An external power source, like an electric motor or internal combustion engine, connects to the drive shaft, which maintains a constant rotation. This movement of the drive shaft results in the back and forth motion of the cylinder block and pistons, leading to suction and dis-charge actions responsible for pumping fluids.

Bearings are commonly used to support the drive shaft, which helps minimize friction and guarantee seamless rotation. Additionally, a seal might be installed to hinder any fluid leakage from the pump.Gears or a flexible coupling are necessary in certain axial piston pump designs where the drive shaft is positioned at an angle with respect to the cylinder block and pistons for power transmission between the two components.The drive shaft is an essential element of the axial piston pump that transmits energy from an outside source to the pump and produces the required motion for fluid pump-ing. It is often constructed of strong steel, aided by bearings, and could have a seal to avoid any leak-age of fluids. [6] [4]

4.5 Valves

Valves play a crucial role in regulating the flow of fluid through an axial piston pump and ensure it moves in the intended direction. Inlet valves and outlet valves are the two primary types of valves uti-lized in these pumps.Valves that regulate the flow of fluid into a pump are called inlet valves. These valves are situated at the inlet port of the pump and usually contain a ball or poppet valve. The valve opens when the pressure inside the pump is less than the pressure of the fluid entering it, enabling fluid to enter and fill up the cylinder bores.Valves that regulate the flow of fluid out of the pump are situated at the outlet port. They usually comprise a valve with a poppet that is spring-loaded and opens when the pressure inside the cylinder bores exceeds that in the outlet port, enabling the fluid to flow into the hydraulic system. [6] [10] One type of axial piston pump may use a spool valve, which is a singular valve that combines the inlet and outlet valves. This valve contains a cylindrical piston that moves within the valve body to regulate fluid flow in the pump. [11] Valves play a crucial role in an axial piston pump as they manage the fluid flow and ensure it moves in the desired direction. These valves can either be separate inlet and outlet ones or combined into a sin-gle spool valve.

4.6 Housing

The housing of an axial piston pump is responsible for giving structural support to the inner parts of the pump and is made of cast iron, aluminum, or steel. It is designed to endure high levels of stress and strain. The typical shape of the housing is a hollow cylinder that has an inlet opening on one side and an outlet opening on the other. These openings are linked to the inlet and outlet valves, and they create a path for the fluid to enter and exit the pump. [6] [11] The pump's internal parts, such as the cylinder block, pistons, and swash plate, are housed within a se-cure enclosure to prevent fluid leakage.A pressure relief valve or other safety mechanisms may be inte-grated into the housing of certain axial piston pump models to avoid harm to the hydraulic system or pump in cases of excessive pressure. The housing is a crucial part of an axial piston pump as it provides support to the internal components and prevents fluid leakage. It includes inlet and outlet ports, cylinder block, pistons, swash plate, and other internal parts of the pump. Usually made of cast iron, aluminum or steel. [6] [8]

4.7 Piston Assembly

The axial bores of the cylinder block serve as the piston's path. This piston is attached to the shoe plate by the shoe joint. This shoe plate is fastened to a swash plate. An automobile typically has between 8 and 12 pistons. They are always present in an even number. They reciprocate in the axial bores as they move in an axial direction.

5 Working Principle

The axial flow variable displacement piston is seen in the illustration. The operational liquid or gas is injected into and ejected from the outlet port and inlet port, respectively. These are enclosed in an iron shell.

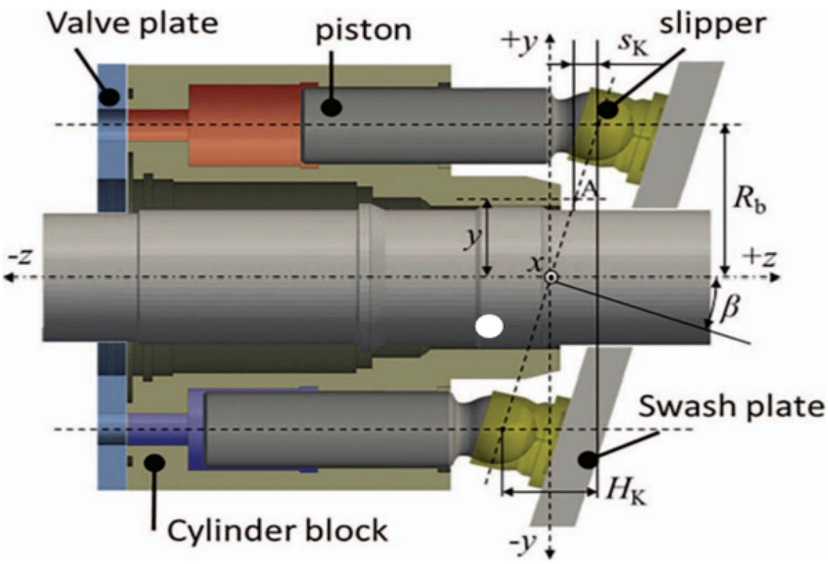

Figure 4: Axial Piston Pump Cross Section

A revolving barrel and swashplate are connected to the driveshaft. Based on the location of the barrel and pistons, the swashplate automatically adjusts. We have two colors for the intake and outflow ports, as illustrated in the image. The upside-down piston is squeezed within the rotating barrel, and the opposite is true for the upside-down piston, which is pressed outside. The swashplate's position leans in one direction or another. To ensure that the piston's placement entirely forms a cycle, the same position is reversed for the following cycle of operation. This facilitates the displacement of gases or liquids from one place to another, namely from the input port to the exit port. In accordance with the swashplate's location, the pistons and barrel both revolve. A cy-lindrical block contains the pistons. The pistons' movement results in a differential in pressure, which draws the inlet liquid or compressed gas into the system. The swashplate is inclined up to 10 to 15 degrees while it is in the upright position. It is known as an axial flow and variable displacement piston for this reason. Reciprocating motion is the name given to the piston's movement. The displacement in the liquid or compressed gasses is caused by the pistons' continuous action, or their suc-tion and discharge. We have less suction when the angle is smaller, and greater suction when the angle is larger. It is referred known as a variable displacement piston because of this. The swashplate angle affects the variable displacement.

6 overview of the design calculations involved in an axial piston pump:

The flow rate, pressure, speed, and other application requirements all affect the diameter and separation of the piston from the shaft in an axial piston pump. The following are some general formulae and recommendations for calculating these dimensions:

1. Piston diameter (Dp): The piston diameter is typically determined based on the required flow rate and the number of pistons. The formula for piston diameter is:

   $$Dp = sqrt((4 * Q)/(\pi * n * L * f * sin(\beta)))$$

   Where: Q = Flow rate n = Number of pistons L = Stroke length of the piston f = Frequency of the pump β = Swash plate angle

2. Piston to shaft distance (R): The stroke length, piston diameter, and number of pistons are commonly used to calculate the piston to shaft distance. The equation for the distance between the shaft and the piston is:

   $$R = Dp/(2 * \tan(\pi/n))$$

   Where: Dp = Piston diameter n = Number of pistons

3. Piston pitch diameter (D): The diameter of the circle on which the piston centre lines lie is known as the piston pitch diameter. The piston pitch diameter formula is:

   $$D = (n * L)/sin(\pi/n)$$

   Where: n = Number of pistons L = Stroke length of the piston

   These calculations are only broad recommendations that could need to be altered depending on the demands of a certain application as well as other elements. For precise design and application requirements, it is advised to consult the manufacturer's technical specifications or a qualified hydraulic engineer.

4. Calculating the displacement volume. The displacement volume is the amount of fluid that the pump moves every revolution. The following formula can be used to compute it:

$$Vd = (\pi/4) * D^2 * L_P * N_P$$

where D is the piston diameter, L_p is the piston length and N_p is the number of pistons

5. Calculating flow rate (Q): The flow rate is the amount of fluid that a pump delivers in a given amount of time. The following formula may be used to compute it:

$$Q = (V_d) * (N)$$

Where, N is Pump speed

6. Calculating pressure: The pressure is the force produced by the pump per unit of area. The following formula may be used to compute it:

$$P = (F_p)/(A_p)$$

Where, Fp is force on piston and Ap is piston area

7. Maximum Cylinder Pressure (P_{max}):

$$P_{max} = Q * F * K_p/(N * Ap) * 2$$

Where, Q is the volumetric flow rate, F is the fluid pressure drop, Kp is the pump constant, N is the rotational speed, and Ap is the piston area

8. 8. The force on the piston can be calculated using the following formula:

$$F_p = PressureDifferential * (A_p)$$

Where, The pressure differential is the difference between the inlet and outlet pressures of the pump.

9. Calculating power: The power is the pace at which the pump does work. The following formula may be used to compute it:

$$Power = (Pressure)x(Flowrate)$$

Where, P is pressure generated by pump and Q is flow rate

10. Calculating efficiency () The ratio of input to output power is known as efficiency. The following formula may be used to compute it:

$$\eta = (Outputpower)/(Inputpower)$$

11. The input power can be calculated using the following formula

$$Inputpower = (Q)x(Pressuredifferential)/(\eta)$$

Where, Q is flow rate and H is efficiency.

For a specific flow rate and pressure demand, these formulas may be used to estimate the ideal size of the pistons and barrel diameter. However, the precise design calculations and specifications may change based on the axial piston pump's individual application and design needs.
To guarantee that the axial piston pump performs well and satisfies the necessary performance requirements, design calculations for the pump must consider the size of the various components.

(a) Calculating the diameter of a piston Based on the needed flow rate and piston speed, the piston diameter is chosen. The amount of fluid that must be moved by the piston in a specific amount of time depends on the flow rate. The pace at which the piston travels is known as the piston speed, and it is correlated with the rotating speed of the pump shaft.

$$Pistondiameter = Q/(2 * \pi * L * N * V)$$

Where, Q is the flow rate in cubic meters per second, L is the piston stroke length, N is the number of pistons, and V is the mean piston speed in meters per second.

(b) Calculation of barrel diameter: The number of pistons and the required flow rate are used to estimate the barrel diameter. The diameter of the barrel must be sufficient to support the necessary number of pistons and to permit the acceptable flow rate. The following formula can be used to determine the barrel diameter:

$$Barreldiameter = (D * N)/(0.8 * \pi)$$

Where, D is the piston diameter and N is the number of pistons.

(c) Calculating the piston stroke length: The piston stroke length is established using the piston diameter and the necessary flow rate. The piston stroke length needs to be sufficient to support the required flow rate while preserving a practical piston speed. The following formula may be used to determine the piston stroke length:

$$Pistonstrokelength = Q/(\pi * D^2 * N * V)$$

Where, Q is the flow rate in cubic meters per second, D is the piston diameter, N is the number of pistons, and V is the mean piston speed in meters per second.

(d) Calculation of the swash plate angle: The swash plate angle is the tilt of the swash plate with respect to the axis of the pump. The length of the piston stroke and the flow rate are both governed by the swash plate angle. The following formula may be used to determine the swash plate angle:

$$\textit{Swash plate angle} = \arctan(Q/(\pi * D^2 * N * V * cos(\alpha)))$$

Where, α is the angle between the swash plate and the pump axis.

(e) Calculation of the cylinder block length: The cylinder block length is established using the required number of pistons and the piston stroke length. The length of the cylinder block must be sufficient to accommodate both the intended piston stroke length and the necessary number of pistons. The following formula may be used to determine the length of a cylinder block:

$$Cylinder\ block\ length = (L * N) + clearance$$

Where, L is the piston stroke length, N is the number of pistons, and clearance is the gap between the end of the cylinder block and the piston at the end of the stroke.

(f) Calculating clearance volume refers to determining the volume of fluid in the cylinder block that is not moved by the piston. To enhance pump efficiency, the clearance volume should be kept to a minimum. The following formula can be used to get the clearance volume:

$$Clearance\ volume = (\pi * D^2 * L)/4$$

Where, D is the piston diameter and L is the piston stroke length.

7 EDUCATIONAL VIDEO OVERVIEW

Briefly introduce the topic of axial piston pump and Introduction: its importance in various industries.
• Explain that the video will showcase the working of axial piston pump using Lua.

Part 1: Overview of Axial Piston Pump

• Explain the components and working of axial piston pump.
• Use animated visuals to demonstrate the flow of fluid through the pump and how it generates pressure.

Part 2: Lua Programming for Axial Piston Pump

• Introduce Lua software and its use in programming axial piston pump.
• Demonstrate how to write code in Lua for controlling the pump's components, such as adjust-ing the swash plate angle and flow rate.

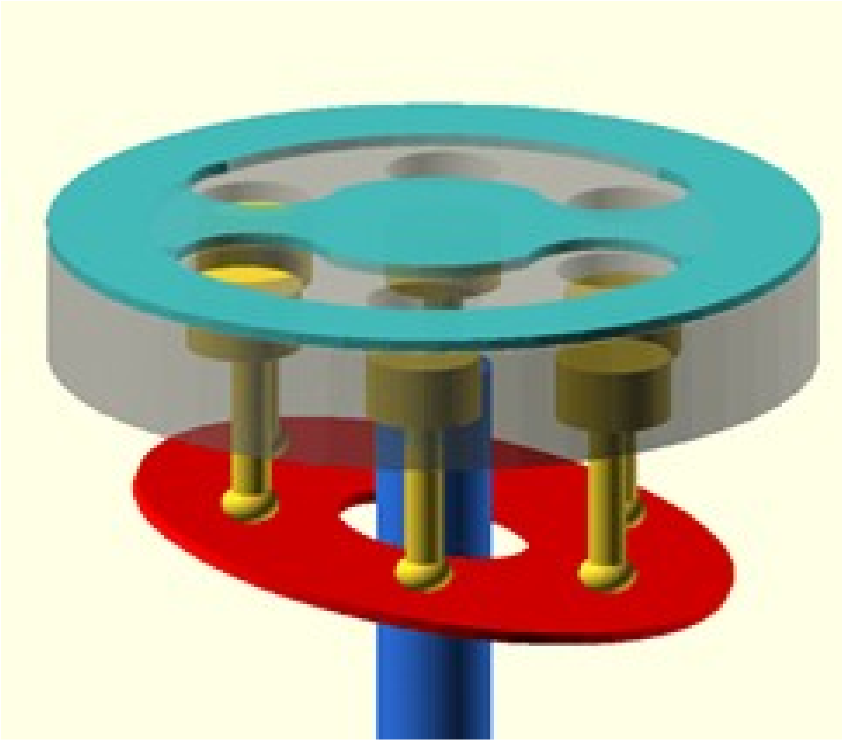

Figure 5: Animation of axial piston pump

Part 3: Simulation of Axial Piston Pump in Lua

• Use the code written in Lua to create a simulation of axial piston pump in action.
• Show how the pump's performance can be adjusted by changing the parameters in the Lua code.

Part 4: Applications of Axial Piston Pump

1. Explain the various industries where axial piston pump is used, such as automotive, aerospace, and manufacturing.
2. Discuss the benefits of using axial piston pump in these industries, such as increased efficiency and durability.

8 ROLE OF ADDITIVE MANUFACTURING IN AXIAL PISTON PUMP

The development of axial piston pumps has undergone transformational changes due to the innovative Additive Manufacturing (AM) technology, enabling manufacturers to generate customized products with increased efficiency and accuracy. The utilization of diverse materials in 3D printing amplifies the functionality and stability of AM products like axial piston pumps making them more practical for challenging industrial conditions such as aerospace and defense applications. Integrating AM technology into pump design op-timization enables engineers to improve pump efficiency while reducing its weight result-ing in cost-effective manufacturing processes that provide a significant competitive edge for companies producing high-quality, tailored products. Moreover, incorporating

AM technology presents limitless opportunities for generating innovative designs with enhanced customization features beyond traditional manufacturing methods' capabilities. [10] [12]

This not only enhances overall productivity but also caters to exclusive customer needs while minimizing material wastage. Hence it is an ideal solution for corporations seeking sustainable growth opportunities within today's fast-paced market environment. Mechanical engineering research aimed at improving pump design through additive manufacturing will undoubtedly result in further advancements that may revolutionize this industry even more significantly. Embracing cutting-edge technologies remains essential for businesses looking towards growth prospects alongside sustainability practices. [11]

In conclusion, utilizing AM provides numerous benefits that enhance production quality processes while minimizing costs significantly; its integration offers a remarkable way for-ward towards achieving sustainable global industrial development practices effectively. While continuing exploration of various materials through 3D printing technologies during axial piston pump manufacture, laying emphasis on optimizing energy savings and waste reduction leads us closer towards better environmental conservation practices. As future developments emerge from integrating AM technology into industries beyond just axial piston pumps production, one thing becomes increasingly clear: innovation knows no bounds; thus, our approach must remain dynamic enough so we can keep up with tech-nological advances proactively adapting ways that enable continuous progress. Ultimately it is now apparent how revolutionary additive manufacturing has been over traditional methods regarding axial piston pumps production - less wasteful yet environmentally friendly- As we continue progressing let us embrace new technologies in all sectors of our lives to achieve a better future. [8]

9 Advantages

(a) axial piston pumps are known for their high efficiency as they have been designed to minimize fluid leakage and offer high volumetric efficiency. This in turn leads to cost savings and reduced energy consumption for the user. To illustrate, a hydraulic system that uses an axial piston pump may consume less power, ultimately resulting in lower energy expenses. [3]

(b) Axial piston pumps have the ability to produce high pressure, which makes them appro-priate for applications that demand high pressure such as hydraulic systems. This feature makes axial piston pumps a perfect fit for heavy-duty machinery like excavators, bull-dozers, and cranes. To illustrate, a 5000 PSI rated axial piston pump can supply the re-quired power to lift heavy loads and perform other high-pressure operations. [1]

(c) Axial piston pumps have a small size and offer a high power-to-weight ratio, which makes them ideal for utilization in limited spaces. This quality is beneficial for industries like automotive and aerospace where space is at a premium. For instance, an axial piston pump can be employed in the hydraulic system of an aircraft to power the landing gear despite the restricted space available. [6]

(d) Axial piston pumps are a dependable option for industrial use due to their longevity and durability. Their ability to endure high temperatures and pressures is attributed to their sturdy construction. They can be used in steel mills as a source of hydraulic power for heavy machinery, and they can withstand the challenging conditions that come with working in such environments. [6]

(e) Axial piston pumps are a dependable and multipurpose option for numerous industrial uses due to their advantageous qualities.

10 DISADVANTAGE

(a) Axial piston pumps can be pricier than other pump types because of their intricate manufacturing process and design. The expense of the pump might play a vital role in the selection procedure, particularly for applications with budget constraints. [10]

(b) High noise levels can be a problem in certain applications of axial piston pumps due to the rapid speed of the rotating components and pressure waves generated by the fluid.

(c) Axial piston pumps have a design that is difficult to repair and maintain due to their complexity. They consist of numerous intricate components which necessitate care-ful assembly, and skilled technicians and specialized equipment are required for maintenance and repairs. [4]

(d) Possible paraphrase: High-pressure operation of axial piston pumps may cause leakage problems, which can arise at the seals or the junction between rotating and stationary parts. Leakage can negatively affect pump efficiency, system performance, and operating expenses.

(e) Excessive noise levels can be a concern for workers' well-being and safety in a facto-ry setting, which is a potential weakness of axial piston pumps. If a high-speed axial piston pump is utilized in the manufacturing process, it could create significant noise levels that might require the installation of noise-dampening equipment or additional safety measures to safeguard workers. This extra equipment or measures would increase the total cost of the pump system.

(f) Repairing a failed component in the pump system can be difficult due to the intricate design of the pump. It might need experts and specific tools which could result in expensive repair charges and extended periods of manufacturing downtime. [2] [1]

11 ALTERNATE SOLUTIONS

(a) Several pistons arranged around a central camshaft are used to operate radial piston pumps. These pistons move in and out of bores located in the pump's housing, causing a change in volume that results in the pumping action. Due to their high-pressure capability and durability, these pumps are commonly utilized as an alternative to axial piston pumps in high-pressure applications, such as hydraulic systems. [6]

(b) A cheaper and simpler alternative to axial piston pumps is gear pumps. These pumps operate with two interlocking gears that move in opposite directions, creating a vac-uum that sucks in fluid and then expels it out of the pump. Gear pumps are typically used in low-pressure situations like lubrication systems and fuel delivery systems, where their lower efficiency is not a major issue. [7] [8]

(c) A type of pump called vane pumps utilizes a cylinder that rotates and has sliding vanes to produce flow. The movement of the vanes in and out, as the cylinder turns, causes a variation in volume, resulting in pumping action. Vane pumps are less effi-cient than axial piston pumps but are still dependable and reasonably priced. They're frequently used for low to medium-pressure applications like power steering systems and transmissions. [12]

(d) A kind of pump called diaphragm pumps utilize a pliable diaphragm to create movement. The motion of the diaphragm generates a change in volume, which leads to the pumping action. In situations where their lower efficiency is not an issue, diaphragm pumps can replace axial piston pumps for low-pressure applications. They are typically found in medical equipment, chemical processing, and water treatment areas. [11]

(e) There are various options available besides axial piston pumps that may be more economical, easier to use, or applicable for different pressure levels. The decision on which pump to use will be based on the particular application needs, operating cir-cumstances, and financial plan. [4]

12 conclusion

Axial piston pumps are an essential part of numerous industrial and mobile applications because of their compact size, high efficiency, ability to handle high pressure, and durability. Nevertheless, they do have some drawbacks like being expensive, complex, noisy, and prone to leakage that can restrict their application in certain situations.

Axial piston pumps are still being studied and improved to enhance their efficiency, make maintenance and repair simpler, minimize noise, and avoid leakage, despite their shortcomings. Additive manufacturing has allowed for the creation of more intricate designs that optimize axial piston pump performance and capabilities.

Other types of pumps like radial piston, gear, vane, and diaphragm pumps may be used as alternative solutions for applications where axial piston pumps are not feasible due to various reasons such as cost or complexity. Nevertheless, it is crucial to evaluate the spe-cific needs of each application meticulously before deciding on a pump type. [3] [4]

The significance of axial piston pumps in contemporary industrial and mobile systems cannot be emphasized enough. With the progression of technology, there will likely be more advancements in their creation, structure, and functionality, resulting in cost-efficient, dependable, and more effective solutions for various applications. [?]

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