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Design, Development & Analysis of Variable Displacement Pump

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ABSTRACT

This research paper presents modification in the radial piston pump design that will offer a variable discharge configuration in addition to the advantages of high efficiency and maximum pressure. Thus objective of project is defined to develop a variable displacement mechanism that will vary the stroke of a single cylinder radial piston pump, which offers to vary the discharge of the pump using manual control. The solution offered is in form of the linkage where in this mechanism is to convert rotary motion of crank into oscillatory output of the output element. The angle of oscillation of the output element is a function of the position of pivot element. The pivot position can be varied as it is placed on a slide. Thus adjustment of the stroke can be done by varying the position of the pivot element. This mechanism is selected because it offers maximum stability and vibration-less performance and nature of mounting of the pivot element which is mounted on a screw slide with accurate adjustment of pivot position that permits continuously variable position change of pivot and stroke of the output. This enables accurate control of the output discharge from the pump linkage.

Index Terms: piston pump, variable displacement piston pump, variable discharge, variable displacement linkage.

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I. INTRODUCTION

A pump is a device that moves fluids or slurries, by mechanical action.

A. Piston pumps

Piston pumps are used for the high pressure applications. These pumps have greater efficiency and simple design and needs lower maintenance. These pumps convert the rotary motion of shaft into reciprocating motion of the piston. The reciprocating piston sucks fluid inside the cylinder when piston retracts in a cylinder and discharges the fluid when piston extends. Generally, these pumps consist of fixed inclined plate or variable degree of angle plate called as swash plate.

When the barrel assembly rotates, the swash plate with the piston slippers slides along the swash plate surface. The stroke length depends on the angle of inclination of the swash plate. When the swash plate is in vertical position, the reciprocating motion cannot take place and hence pumping of the fluid cannot take place. When swash plate angle increases, the piston reciprocates in the cylinder barrel. The stroke length of the piston increases with increase in the swash plate angle. During one half of the rotation, the pistons come out of the cylinder barrel and the volume of the cylinder barrel increases. During another half of the rotation of shaft, the pistons move into the cylinder barrel and the barrel volume decreases. This is responsible for sucking the fluid in and pumping it out. These pumps are positive displacement pump. This pump can be used for both liquids and gases. Piston pumps are basically of two types:

1) Axial piston pumps
2) Radial piston pumps

B. Axial Piston Pump

Axial piston pumps are positive displacement pumps which converts rotary motion of the input shaft into an axial reciprocating motion of the pistons. These pumps have a number of pistons arranged in a circular array within a housing which is known as a cylinder block, rotor or barrel. This cylinder block rotates by shaft aligned with the pistons. These pumps have sub-types as:

1) Bent axis piston pumps
2) Swash plate axial piston pump

1) Bent-Axis Piston Pumps

In these pumps, the pistons are reciprocated by bending the axis of the cylinder block. The cylinder rotates at an angle which is inclined to shaft. The cylinder block is set at an offset angle with the shaft. The cylinder block contains pistons along its periphery. These piston rods are connected with the flange. These pistons are moved in and out of their bores as the distance between shaft flange and the cylinder changes. A universal link connects the block to the shaft which provides alignment and a positive drive.

2) Swash Plate Axial Piston Pump

A swash plate translates the rotary motion of a shaft into the reciprocating motion. It has a disk attached to a shaft. If the disk is aligned perfectly perpendicular to shaft; the disk will rotate along with the shaft without any reciprocating effect. Similarly, inclined shaft will oscillate. This apparent linear motion increases with increased angle between disk and the shaft called as offset angle. The apparent linear motion can be converted into reciprocating motion by a follower that does not turn with the swash plate.

In swash plate axial piston pump pistons are aligned coaxially to a shaft via a swash plate to pump a fluid. The axial reciprocating motion of pistons is obtained by a swash plate which is either fixed or has variable degree of angle. As the piston barrel assembly rotates, the piston rotates around the shaft with the piston shoes in contact with the swash plate. The piston shoes follow the surface of the swash plate and the rotating motion of the shaft is converted into the reciprocating motion of the pistons. When the swash plate is perfectly perpendicular to the shaft; the reciprocating motion does not occur. Increase in the swash plate angle causes the piston to follows the angle of the swash plate surface and because of that it moves in and out of the cylinder barrel. The piston comes out of the cylinder barrel during one half of rotation thereby generating an increasing volume; while during other half of the rotating, the pistons move into the cylinder barrel generating a decreasing volume. This reciprocating motion of the piston results in the sucking in and pumping out of the fluid. The capacity of pump can be controlled by varying the swash plate angle by attaching separate hydraulic cylinder. The pump capacity increases with increase in the swash plate angle and decreases with decrease in angle. The cylinder block and the shaft in this pump are placed on the same centerline. The pistons are connected through shoes and a shoe plate that rest against the swash plate. These pumps can be designed for a variable displacement capability.

C. Radial Piston Pump

The piston pump has number of pistons aligned radially in a cylindrical block. It consists of a pintle, a cylinder barrel, a pistons and a rotor which contains a ring. The pintle causes the fluid in and out of the cylinder. Pistons are located in radial bores around the rotor. The piston shoes rest on an eccentric ring which causes them to reciprocate as they rotate. The stroke of the pumping piston is determined by eccentricity. Each piston is connected to inlet port when it starts extending while it is connected to the outlet port when it starts retracting. This connection to the inlet and outlet port is performed by the timed porting arrangement in the pintle. For initiating a pumping action, the reaction ring is moved eccentrically with the pintle or shaft axis. As the barrel rotates, the pistons travel outward. This sucks the fluid in the barrel as the cylinder passes the suction port of the pintle. It is continued up to the maximum eccentricity. When the maximum eccentricity is passed by the piston, pintle is forced inwards by the reaction ring. This causes the fluid to flow out of the cylinder and enter in the outlet port of the pintle.

D. Objective

In hydraulic power systems, variable displacement pumps save power, control the motion of a load accurately, safely and in an economical. The displacement varying mechanism and low power and low weight of variable displacement piston pump are most suitable for control of high power applications.

The bent axis piston pump is used in most hydraulic power systems because of its high performance and high efficiency. It is also used at variable conditions of flow, pressure, speed and torque Axial piston pumps with variable flow have possibilities for controlling the flow by change of pressure. Volumetric control of the pump provides application of these pumps in complex hydraulic systems, especially in aeronautics and space engineering.

The major problem in application of the bent axis piston pump is its high cost over that of the radial piston pump, which is in the range of 5 to 6 times the cost of radial piston pump. Hence it is necessary develop a modification in the radial piston pump design that will provide a variable discharge configuration with added advantages of high efficiency and maximum pressure.

Therefore objective of project is defined to develop a variable displacement mechanism that will enable variable stroke of radial piston pump, thereby offering to vary the discharge of the pump manually.

E. Concept of Eccentric Pivot Mechanism Using Four Bar Kinematic Linkage

This mechanism is to convert rotary motion of crank into oscillatory output of the output element. The angle of oscillation of the output element depends on position of pivot element. The pivot element position can be varied because it is placed on a slide. Thus adjustment of the piston stroke can be done by varying the position of the pivot element. This mechanism is selected because it offers maximum stability and vibration-less performance and nature of mounting of the pivot element which is mounted on a screw slide with accurate adjustment of pivot position permits continuously variable position of pivot and therefore stroke of the output. This enables precise control of the output discharge from the pump linkage. The mechanism is basically an inversion of four bar kinematic linkage.

II. METHODOLOGY

1) System design as to and theoretical derivation of dimensions of the adjustable stroke mechanism kinematic linkage using Kinematic overlay method using Auto-Cad software.

2) System Design and theoretical derivation of dimensions of the pump activation linkage for the above derived kinematic linkage system
3) System Design and theoretical derivations of linkage as for strength criterion for given pressure and flow specifications
4) Selection of pump and drive for circulation of oil through the hydraulic system to get desired flow rates.
5) Selection of motor and drive system for the eccentric arrangement to deliver desired power to pump system.
6) Development of PID diagram for the circuit of hydraulic oil from the modules to the system and flow from the system back to the oil tank.
7) Design validation of the stress produced in the parts like input shaft, eccentrics, connecting link, output link, control link, piston rod, displacer link, using ANSYS software.
8) Fabrication: Suitable manufacturing methods will be employed to fabricate the components and then assemble the test set –up.

A. Schematic of Test Rig:

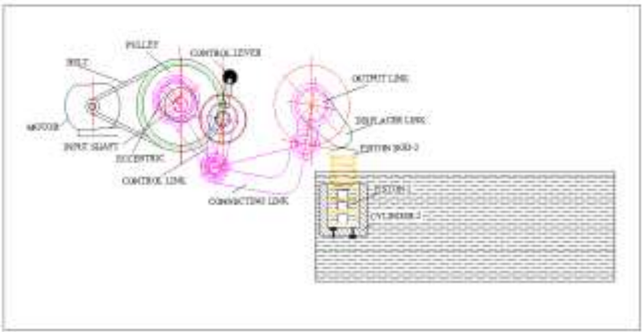

Fig. 1 Schematic of Test Rig

1) Construction

In above test rig we provide motor which drives the pulley the pulley rotates with uniform velocity to the pulley input shaft is attached so shaft rotates with the pulley the eccentric is mounted on the shaft which is attached to the connecting rod, the other end of connecting rod is attached to the connecting link to which output yoke is connected. Adjusting link is provided which is mounted on the screw slide this is called as control lever which can be adjusted with control knob. The position of control lever can be changed because it is placed on a screw slide. Displacer link is provided on the output shaft. This displacer link is in contact with the piston rod of the pump the piston rod is provided with spring for return stroke.

2) Working

As the pulley rotates input shaft rotates so the eccentric rotates. Rotation of eccentric causes connecting rod to oscillate therefore the connecting link also oscillate which causes output yoke to rotate through angle. The rotation of output yoke can be varied by the control link because it is mounted on the slide. The displacer link is placed eccentrically with output shaft so as the movement of the output yoke increases the piston rod displaces more and more stroke is obtained in the pump which leads to more discharge so the discharge of the pump can be varied by varying the movement of output yoke. This can be varied by the control link.

So by this mechanism attached with the spare pump we can vary the discharge of a pump.

III. EXPERIMENTAL RESULTS

Prototype is manufactured on the basis of Analytical as well as theoretical solutions on the safety considerations and testing is conducted to calculate actual flow rate and efficiency.

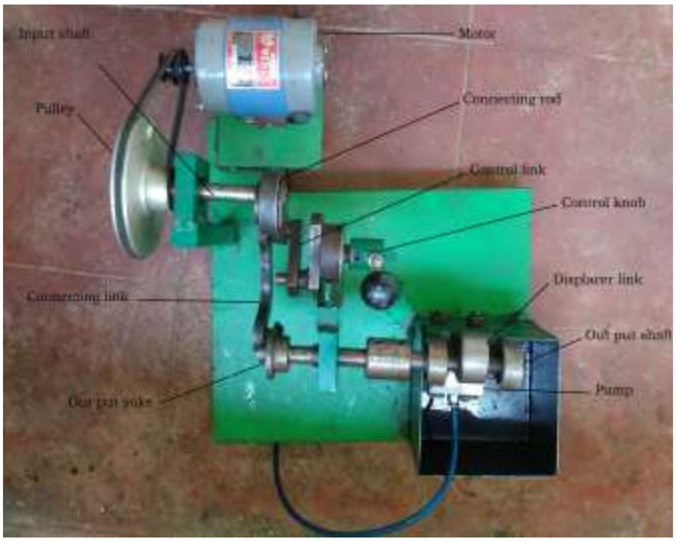

Fig. 2 Experimental Test Setup

Actual Flow Rate = Volume in beaker /Time

Theoretical Discharge per Stroke
= Area of Piston × Displacement

Theoretical Discharge per Minute
= Theoretical Discharge per Stroke × Rpm

Volumetric Efficiency
= Actual Flow Rate /Theoretical Flow Rate

A) Observation Set-1: Control link at 0^0 position
Procedure:

1) Position the control linkage at 0^0 position

2) Start pump motor

3) Maintain input speed at input =100 rpm

4) Collect 100 ml of oil in measuring beaker

5) Note time for collecting 100 ml of oil

SR. NO.	SPEED (RPM)	VOLUME IN BEAKER (ml)	TIME (second)	FLOW RATE (LPM)
01	100	100	189	0.032
02	200	100	94	0.064
03	300	100	65	0.092
04	400	100	49	0.122
05	500	100	40	0.15

Table 1. Observation table

Sr. No .	Speed (rpm)	Actual flow rate (lpm)	Theoretica l flow rate	Volumet ric efficiency
01	100	0.0317	0.036	88.89
02	200	0.063	0.073	87.67
03	300	0.092	0.11	83.64
04	400	0.122	0.147	82.99
05	500	0.15	0.183	81.97

Table 2. Observation table

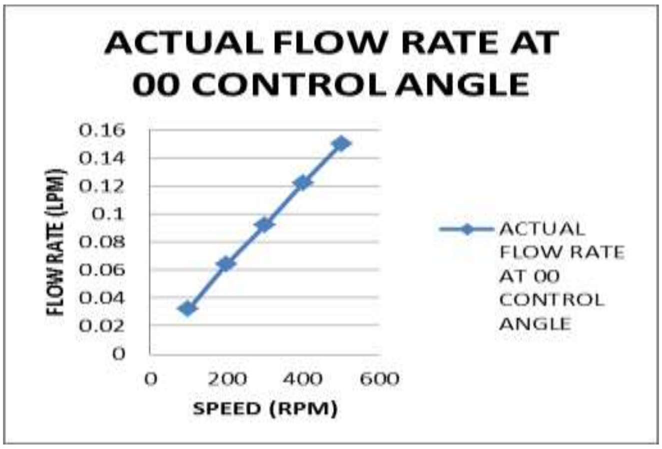

Fig. 3 Actual flow rate vs. speed

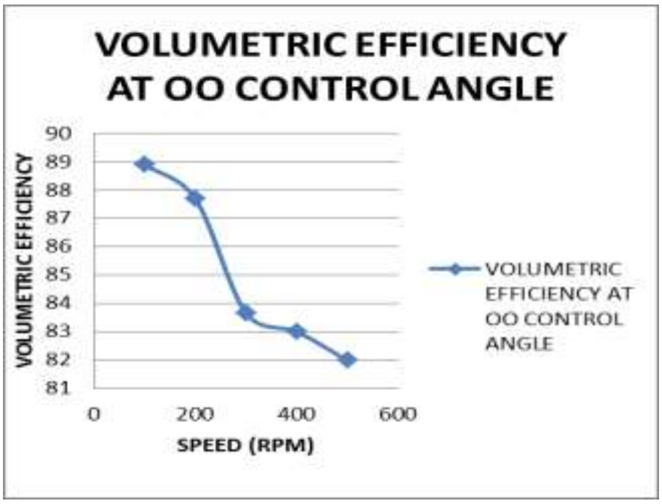

Fig. 4 Volumetric efficiency vs. speed

Similarly observations are taken for 20, 40, 60, 80, 100 and 120 degree angular position of control link.

B) Comparative Graph Of Flow Rate Vs Speed At Various Control Angles

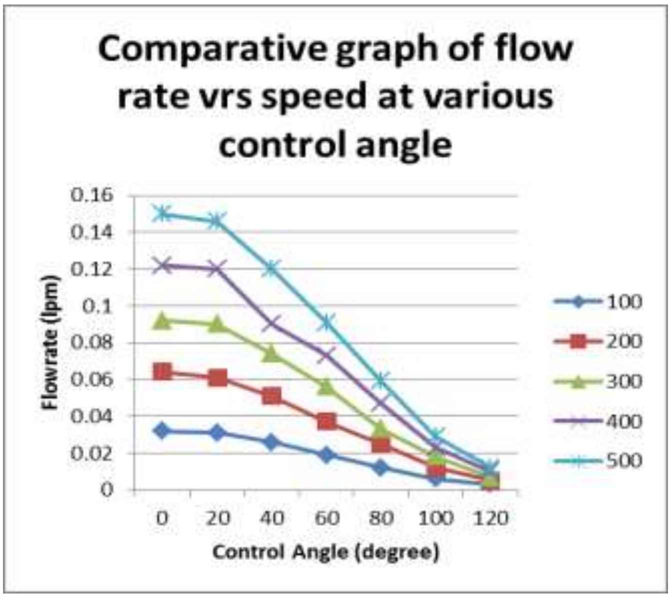

Fig. 5 Flow rate vs. speed at various control angle

IV. CONCLUSION

1) It is seen that the discharge from the pump reduces at the control angle is changed from o degree to 120 degree
2) Volumetric efficiency drops slight as the speed in all cases of control angle.
3) From the seen characteristic of flow in each control angle it can be safely assumed that the discharge of the pump increases with increase in pump speed for all control angles.
4) Precise control of the control angle will provide a wide range of flow rates therby the pump will find application in multiple industry

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