Development of compact electro gear pump for airborne applications

Jeyakumar R[1] , Balasubramanian K[2] , Ramamoorthi R[3] , Ramakrishnan T
[1, 2, 3] Department of Mechanical Engineering,
Sri Krishna College of Engineering and Technology, Coimbatore, Tamilnadu, India.
[4] Department of Mechanical Engineering,
Sri Eshwar College of Engineering, Coimbatore, Tamilnadu, India.

ABSTRACT

The gear type rotary positive displacement pump finds its application in the area of avionics thermal cooling systems. The electronic systems generate lot of heat while in operation. Unless this heat is properly dissipated, the proper functioning of the electronic systems cannot be ensured. Hence to ensure proper supply of coolant liquid under all circumstances of variation of viscosity, pressure and speed, these pumps are used. This pump being a part of airborne system, it has to meet the quality requirements specified by environmental test specification. Present work aims at the development of a design methodology for a gear type rotary positive displacement pump and analysis of the design to obtain maximum efficiency. The clearance between the rotor and the housing plays an important role in the performance of the pump. Therefore importance is given in proportioning the parts of the pump. Based on the performance equations, the dimensionless efficiency curves are plotted to predict the behavior of the pump, which solely depends on the geometry of the pump parts. Alterations of the physical dimensions of the unit are discussed in terms of effect on the performance characteristics. Effort has been made in the report to derive the optimum proportioning of pump parts to achieve a given performance requirement. The results were compared for the operating conditions. It is concluded from the present work, that the ratios of the geometrical dimensions of the gear and the housing is satisfactory for a given range of viscosity and is suitable for medium pressure continuous duty applications.

Keywords : positive displacement pump , viscosity , thermal cooling, efficiency , geometrical dimensions etc

1.1 INTRODUCTION

Spur gear pump is a Positive displacement pump universally used for fluid power systems. As the name implies, a positive displacement pump ejects a fixed amount of fluid into the hydraulic system per revolution of pump shaft rotation, Such a pump is capable of overcoming the pressure resulting from the mechanical loads on the system as well as the resistance to flow due to friction these are the two features which are desired of fluid power pumps, these pumps have High-pressure capability, small, compact size, High volumetric efficiency, Small changes in efficiency throughout the design pressure range, Great flexibility of performance.

Positive displacement pumps are used generally to pump liquids having viscosities that lie in rather a limited range. It would be possible to pump liquids of extremely high viscosities even more efficiently if clearances were designed specifically for a particular service intended.

The slip increases with the cube of clearance and viscous drag increases inversely with clearance, there is an optimum value of clearance which will result in a minimum loss of power. If clearance is designed to fulfill this requirement under the specified operating conditions, best efficiency can be obtained over a wide range of operating conditions. In order to determine best clearances for the various elements of the pump, losses in power due to slip and viscous drag are added and the clearance that makes the total power loss for each element a minimum is then determined by minimizing the equation for power loss in terms of clearance.

1.2 FEATURES AND OPERATING PRINCIPLE

Positive displacement pumps are hydrostatic machines. They operate with a positive transfer and should not work against a closed system.

All rotary pumps are designed after the same principle. Two rotors are arranged on parallel shafts and driven by an external synchronous gear box. The rotors rotate in opposite directions to each other. Small radial and axial clearances assure that they have no contact with each other, or the pump body. The rotors are designed to form a barrier between the suction and pressure side of the pump in any position. The sealing is only maintained by narrow gaps. There are no additional seals or valves.

The increasing cavity between the rotors on the suction side is filled with the fluid. The fluid is displaced in a circumferential direction and discharged on the pressure side as the cavity between the rotors is collapsing. This generates a constant flow from the suction to the discharge side of the pump. Rotary pumps ensure a gentle fluid transfer with minimum stress or damage to the product.

Rotary pumps ensure a gentle fluid transfer with minimum stress or damage to the product.

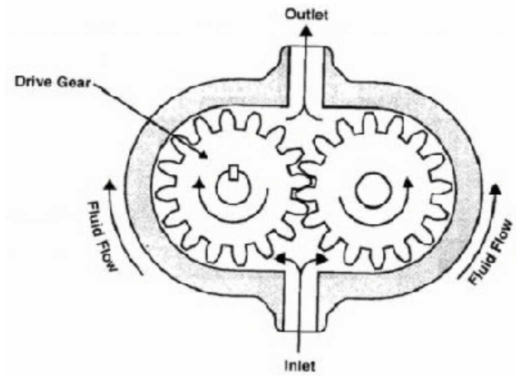


Fig. 1.1 External Gear pump

External gear pump shown in Fig. 1.2 develops flow by carrying fluid between the teeth of two meshing gears. One of the gears is connected to the prime mover.

The second gear is driven as it meshes with the driver gear. Oil chambers are formed between the gear teeth, the pump housing, and the sides wear plates. The suction side is where teeth come out of mesh, and it is here where the volume expands, brining about a reduction in pressure to below atmospheric pressure. Fluid is pushed into this void by atmospheric pressure because the oil supply tank is vented to the atmosphere. The discharge side is where teeth go into mesh, and it is here where the volume decreases between mating teeth. Since the pump has a positive internal seal against leakage, the oil is positively ejected into the outlet port.

The higher the discharge pressure, the lower the volumetric efficiency because internal leakage increases with pressure. The rated pressure of a positive displacement pump is that pressure below which no mechanical damage due to overpressure will occur to the pump and the result will be long reliable service life. Too high a pressure not only produces excessive leakage but also can damage a pump by distorting the casing and overloading the shaft bearings. This brings to mind once again the need for overpressure protection. Also keep in mind that high pressures occur when a large load or resistance to flow is encountered. In general, the gear pumps are the least expensive but also provide the lowest level of performance. In addition, gear pump efficiency is rapidly reduced by wear, which contributes to high maintenance costs. The volumetric efficiency is greatly affected by the following leakage losses, which can rapidly accelerate due to wear.

- Leakage around the outer periphery of the gears
- Leakage across the faces of the gears
- Leakage at the points where the gear teeth make contact

1.3 GEAR PUMPS SYSTEM REQUIREMENTS

The inlet vacuum must be controlled in order to realize expected pump life and performance. The system design must meet inlet pressure requirements during all modes of operation. Expect lower inlet pressures during cold start. It should improve quickly as the fluid warms.

1.4 SYSTEM PRESSURE

It is a dominant operating variable affecting hydraulic unit life. High system pressure, resulting from high load, reduces expected life. System pressure must remain at, or below, rated pressure during normal operation to achieve expected life.

1.5 SPEED

Maximum speed is the limit recommended for a particular gear pump when operating at rated pressure. It is the highest speed at which normal life can be expected.

The lower limit of operating speed is the minimum speed. It is the lowest speed at which normal life can be expected. The minimum speed increases as operating pressure increases when operating under higher pressures, a higher minimum speed must be maintained

1.6 TEMPERATURE AND VISCOSITY

Temperature and viscosity requirements must be concurrently satisfied. High temperature limits apply at the inlet port to the pump. The pump should run at or below the maximum continuous temperature. The peak temperature is based on material properties.

1.7 LINE SIZING

The pipe sizes are chosen to accommodate minimum fluid velocity to reduce system noise, pressure drops, and overheating. This maximizes system life and performance. The inlet piping is designed in such a way that maintains continuous pump inlet pressure above 0.8 bar absolute during normal operation. The line velocity should not exceed the values given in this table 1.1.

Table 1.1 Maximum line velocity

Particulars	Maximum velocity in m/s
Inlet velocity	2.5
Outlet velocity	5.0
Return velocity	3.0

2. 0 DEVELOPMENT OF PUMP

This paper is aimed at the indigenization development of a miniature pump motor unit used in a Podded Electronic Warfare (EW) system. The Podded EW system, which is basically an active electronic counter Measure System include a forced liquid cooling system for cooling the electronic components such as ICs, power supply, PCBs etc . The miniature pump is used in this forced liquid cooling system to circulate the primary coolant Fluoro Carbon through the cold plates and submerged heat exchanger.

The development of the pump unit involves two major activities namely development of Pump and development of Motor and finally these two are to be assembled and evaluated for its Design and Performance.

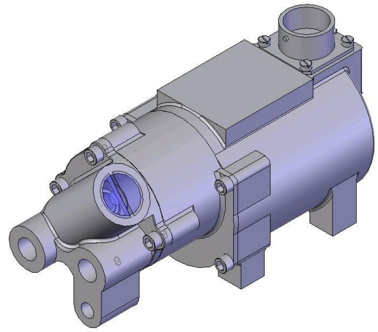


Fig. 2.1 Pump motor unit assembly

The pump motor assembly consists of the following parts.

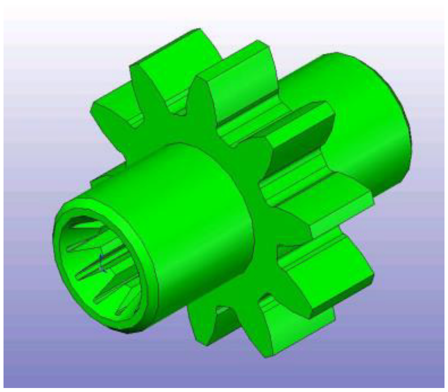


Fig. 2.2 Driver gear shaft

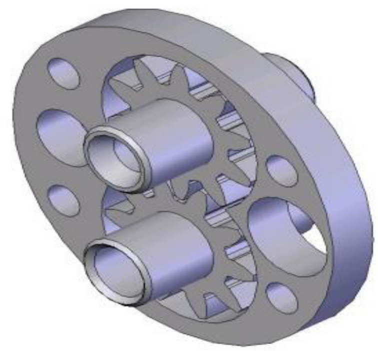


Fig. 2.3 Drive and Driven gear shaft assembly

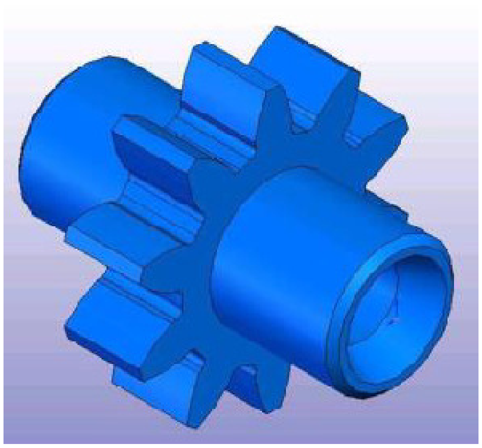


Fig. 2.4 Driven gear shaft

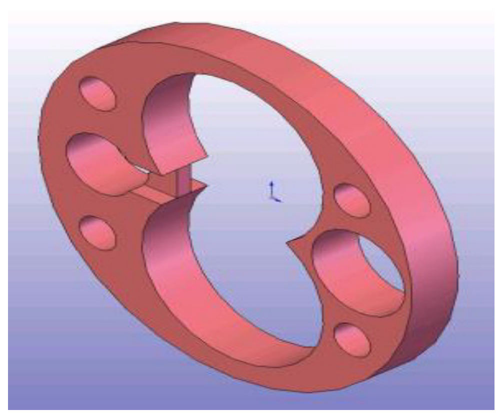


Fig. 2.5 Spacer

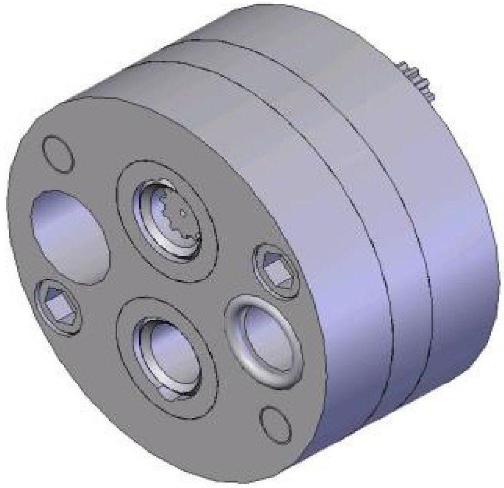


Fig. 2.6 Cartridge assembly

The driver gear shaft and the driven gear shaft are housed in a spacer as shown in Fig. 2.3. There are two holes in the spacer one is bigger diameter and the other is smaller. The fluid enters through the bigger hole , the inlet and leaves with pressure through the outlet , smaller diameter hole. The entire unit is made out of modular construction; this entire assembly is covered with front and rear cartridges as shown in Fig. 2.6. The two diagonal holes of the spacer are used to mount the front and rear cartridges using dowel pins. The other two diagonal holes are used to clamp firmly the entire cartridge assembly by using two socket headed screws. This entire cartridge assembly is housed in the pump interface.

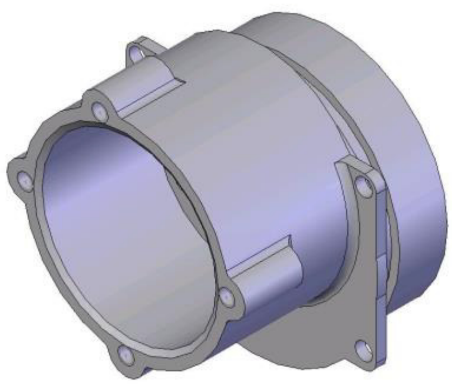
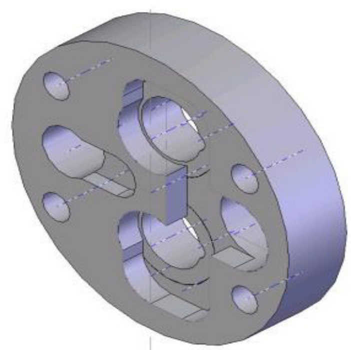
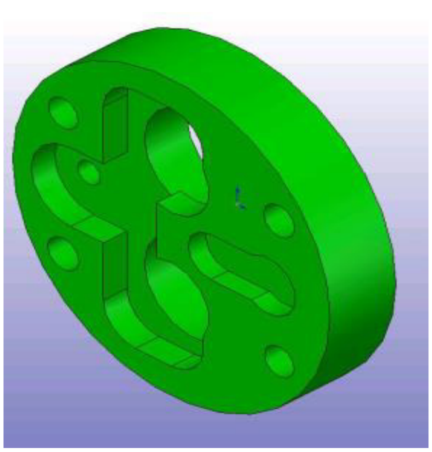


Fig. 2.7 Pump Interface



2.8 Front Cartridge



2.9 Rear Cartridge

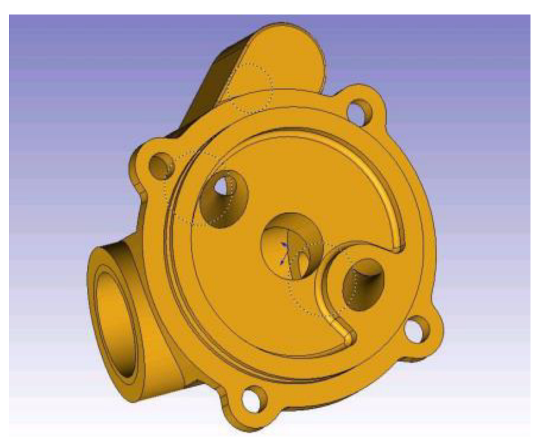


Fig. 2.10 Front cover

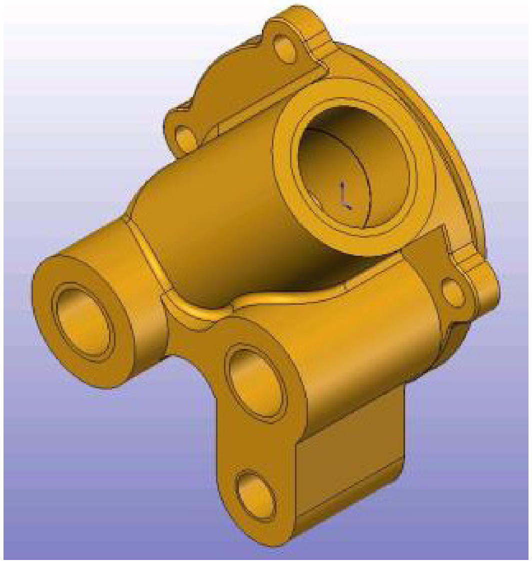


Fig. 2.11 Front cover

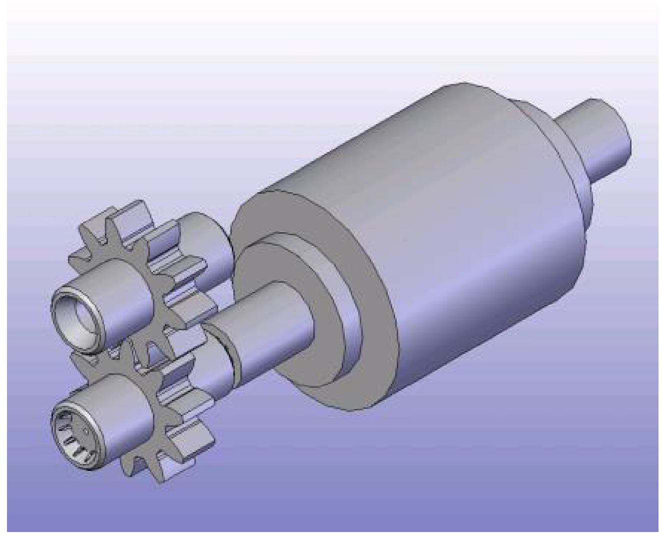


Fig. 2.12.Rotor Pinion/gear assembly

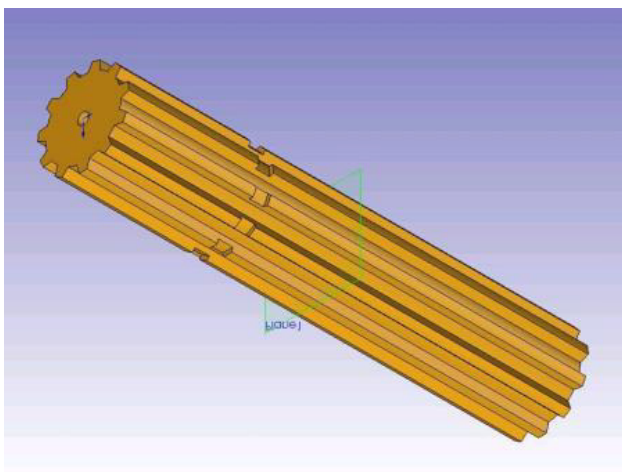


Fig. 2.13 Spline shaft

The rotor rotates the power from the rotor is transmitted through spline shaft to pinion & pinion drives the follower. In addition to all these, a pressure relief mechanism is housed in the front cover to avoid danger of over shooting of pressure. There is no separate cooling system provided, the fluid itself is circulated through the rotors haft and the spline, the same fluid is used even to supply lubrication to the motor and gear shaft journal bearings.

3.0 PROMINENT FEATURES OF THE COOLING SYSTEM

The cooling system is given in this section for an overall understanding of the functioning of all major subsystems. This is a closed loop coolant circulating system mounted in pod. This is employed to remove and reject the heat generated by the electronic components to the environment. The various components of this system shown in fig. 3.1, include the cold plates, submerged heat exchanger mounted in a cooling tank, pump motor unit, boot strap expansion reservoir, switches, control valves, couplings along with necessary piping and the interlock arrangements for system protection etc.

The pump-motor unit (6) is employed to circulate the coolant and the coolant passes through the cold plates and collects the heat generated from the electronic units mounted on them. While passing through the heat exchanger (3) submerged in a secondary coolant i.e, the water-methanol mixture, the heat is rejected to this secondary coolant. The ram air entering the coolant tank through the inlet scoop (1) bubbles through the heat exchanger surface in the water-methanol mixture, the heat is rejected to this secondary coolant. The ram air entering the coolant tank through the inlet scoop (1) bubbles through the heat exchanger surface in the water methanol mixture and carry the heat to the environment through an outlet scoop (2). A negative g-valve (4) in the scoop prevents loss of the secondary coolant during maneuvers. The temperature of the coolant thus obtained from the heat exchanger is low enough to maintain the electronic components within a reliable operating temperature envelope.

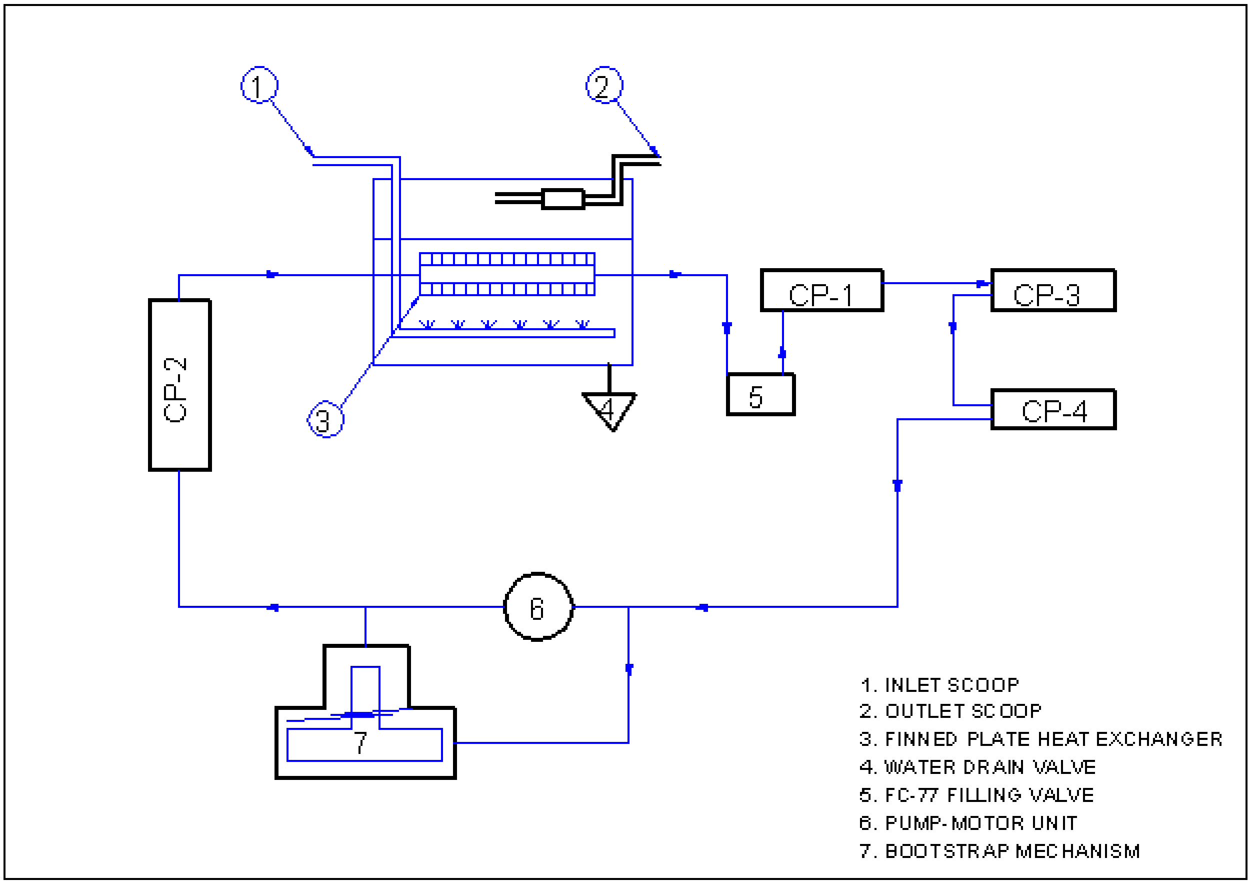


Fig-3.1 Schematic Diagram of Cooling System

CONCLUSION

It must be pointed out that the diagrams given here can be used to design any particular pump, since there have been numerous limitations placed upon them by the assumptions made in the derivations. The generalizations, however, that have been developed can be used as guides in development of pumps of the rotary positive displacement type. The graphical diagrams for certain elements in the drawing can be deduced and used as suggested. It is concluded that the ratios of the geometrical dimensions of the gear and the housing is satisfactory for a given range of viscosity and is suitable for medium pressure continuous duty applications.

References

1 Woo, Sangbeom, and Andrea Vacca. "Experimental Characterization and Evaluation of the Vibroacoustic Field of Hydraulic Pumps: The Case of an External Gear Pump." *Energies* 13, no. 24 (2020): 6639.

2 Zhu, Deming, Yongling Fu, Xu Han, and Zhufeng Li. "Design and experimental verification on characteristics of electro-hydraulic pump." *Mechanical Systems and Signal Processing* 144 (2020): 106771.

3 Komagata, Mitsuo, Tianyi Ko, and Yoshihiko Nakamura. "Design and development of compact ceramics reinforced pump with low internal leakage for electro-hydrostatic actuated robots." In *IFToMM World Congress on Mechanism and Machine Science*, pp. 2439-2448. Springer, Cham, 2019.

4 Padovani, Damiano, Søren Ketelsen, Daniel Hagen, and Lasse Schmidt. "A self-contained electro-hydraulic cylinder with passive load-holding capability." *Energies* 12, no. 2 (2019): 292.

5 Gamez-Montero, Pedro Javier, R. Castilla, and E. Codina. "Methodology based on best practice rules to design a new-born trochoidal gear pump." *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science* 232, no. 6 (2018): 1057-1068.

6 Gamez-Montero, Pedro Javier, Piotr Antoniak, Robert Castilla, Javier Freire, Justyna Krawczyk, Jaroslaw Stryczek, and Esteve Codina. "Magnet-sleeve-sealed mini trochoidal-gear pump prototype with polymer composite gear." *Energies* 10, no. 10 (2017): 1458.

7 Zhu, Deming, Yongling Fu, Xu Han, and Zhufeng Li. "Design and experimental verification on characteristics of electro-hydraulic pump." *Mechanical Systems and Signal Processing* 144 (2020): 106771.

8 R. Hadekal "Displacement pumps and motors", London,Sir Isaac Pitman and sons Ltd.

9 Lev Nelik., "Centrifugal and Rotary pumps, fundamentals with applications, New yark , CRC press.

10 Cherkassky V.M., "Pumps fans Compressors‟, MIR Publishers, Moscow

11 Anthony Esposito, " Fluid Power with Applications",Prentice –Hall International, Inc., a. London.

12 Peter Lynwander, " Gear Drive Systems, Design and application", Marcel Dekker, Inc., New York

13 Roger E Hatten, " Introduction to Hydraulic Fluids", Newyork, Reinhold Publishing Corporation.