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A Study on Effect of Operating Conditions on Gerotor Pump Performance

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ABSTRACT

One of the important accessories of the lubrication system of an aero-engine is the oil pump which consists of multiple pumps with tandem gerotor elements housed in a single casing. This paper presents the volumetric efficiency variation of a single-stage gerotor pump specially designed for aero-engine by conducting experiments at on and off-design conditions and comparing it with the CFD analysis. A Gerotor pump having fixed geometrical parameters designed based on a mathematical 1D model using MatLab and AMESim is manufactured and tested. Performance evaluation of these pumps for pressure and temperature has been discussed in this paper. Commercial CFD code ANSYS-Fluent with a standard k-ε turbulence model has been used for performance evaluation of gerotor pump. Flow characteristics studies on the prototype pump indicate that simulation results closely matched the experimental data. The study concludes that the simulation method adopted is appropriate for predicting the performance of the gerotor pump and the contribution of outlet pressure to the pump volumetric efficiency is significant.

Keywords: Gerotor pump; Trochoidal profiles; Matlab; Amesim; CFD; Volumetric efficiency

1. INTRODUCTION

Gerotor Pump is widely used for lubrication systems in automobile and aeronautic industries. The main function of the lube pump is to circulate the oil from the tank and deliver it under pressure to the engine. The other pump scavenges the oil coming from the various parts of the engine and returns it to the tank.

Compactness, reliability, and flow control are the main advantages of the gerotor pump. The term Gerotor stands for "GEnerated ROTOR". In the gerotor pump, the inner rotor is connected to the prime mover and it drives the outer rotor. The outer rotor rotates freely within the stator ring or housing. The inner rotor has many lobes equal to one less than the number of teeth of the outer rotor. Suction and delivery of oil are achieved by the variation in the volume of a fixed number of chambers created between the inner and the outer rotor. The volume of the chambers keeps on changing as the inner rotor drives the outer rotor. At the inlet, the volume of the chamber increases which creates suction and draws the oil from the inlet port. As the inner rotor rotates further, the chamber volume starts decreasing and pushing the oil towards the delivery side. Gerotor elements are the critical parts that dictate the overall performance of the pump.

Several studies have been carried out in the last few decades to understand the performance of gerotor pumps[1–2]. In the aeronautical field, gerotor pumps are used as oil pumps for lubrication of helicopter gearboxes[3] and main engine bearings[4]. The development of a simulation model for instantaneous and average flow is a prerequisite for performance evaluation.

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Fabiani *et al.*[1] presented the geometric and kinematic aspects of the modeling and simulation of gerotor pumps. A simulation model was developed using Amesim software and results were compared with experimental results. A CFD modeling approach was adapted by various researchers[5-8] for a better understanding of flow dynamics inside oil pumps. Sureshkumar *et al.*[5-6] studied flow dynamics inside the pump and presented the effect of inlet condition on pump performance. Zhang, Perng, and Laverty[7] developed a CFD model to study the flow ripples. Andrea *et al*.[8] carried out optimisation of asymmetric gerotor profile through an algorithm and but their study was focused on the influence of geometric parameters on the performance indexes. Heisel and Mishev[9] also carried out simulation work with PUMPLINX software to study the hydraulic characteristic of gerotors. Ippolitiet all[10] studied the performance of a gerotor pump at various conditions of inlet pressure. Haoliu *et.al*[11] presented a new K-floid profile and conducted a CFD simulation. Min-Choel Lee, *et al*.[12] presented estimation of theoretical flowrate using gerotor chamber areas.

This paper aims to discuss the performance evaluation of a single-stage gerotor pump based on known methods for various design points for temperature and pressure. Parametric studies of Gerotor pumps under the operating conditions selected in this work have not been reported earlier. In the present work, firstly theoretical flow rate has been estimated using a 1D simulation model without consideration of pump clearances, then 3D CFD model has been developed with consideration of internal clearances. Simulation results have been compared with experimental results. Further, the effect of operating conditions like speed, temperature, and outlet pressure on performance has been studied.

This work shows that the 1D method can be effectively used for estimation of theoretical flow rate during the preliminary design stage of gerotor pump followed by more accurate performance predictions using CFD simulation. Thus, this technique enables the designer for quicker modification and more concrete control over the performance of the pump.

1.1 Gerotor Pump

The outer and inner profile of rotors is described by Fabiani *et al.*[1] as shown in Fig. 1. Figure 1 illustrates that the outer rotor is drawn by N circular arc with centers at a distance K from the center O1. The profile of the inner rotor is trochoid and it is conjugated with an outer rotor. Thus if the inner rotor rotates by φ angle then the outer rotor rotates by $\left(\varphi.\frac{N-1}{N}\right)$ angle, where N is the number of lobes in the outer rotor.

The inner rotor is driven by a prime mover and the outer gear is driven by the motion of the inner rotor. This results in an increasing volume between the inner and outer rotor. This increasing volume decreases the pressure in the volume, which allows pushing the fluid into the pump. On another side, it creates a decreasing volume between the gears. This decreasing volume increases the pressure, subsequently squeezing the fluid out of the pump. Kidney shape inlet and outlet ports are designed which facilitate entry and exit of oil.

The operating conditions of the pump are major factors that influence the performance of the gerotor pump. Thus it is important to design the gerotor pump in terms of the better efficiency and longer life of the pump.

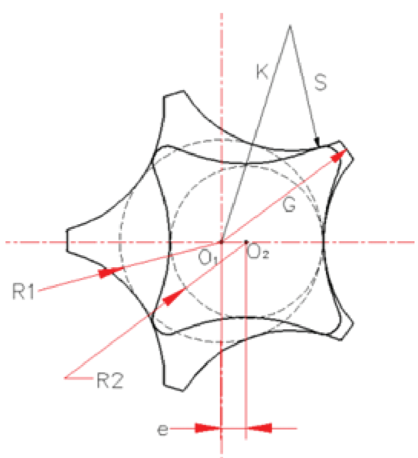

Figure 1. Geometrical parameter of gerotor pump.

1.2 Estimation of Theoretical Flow Rate

In the previous work by Hussain *et al.*[13], a 1D simulation model was developed which facilitates the design of pump profile and estimates volume at various angles depending on the geometrical parameters. This model was developed using advanced modeling environment for simulation (AMESim) software to estimate theoretical flow rate without considering leakage flow with this model, using MatLab, based on input geometrical parameters (Table 1), the profile of the gerotors is generated and estimated area variation of the single-chamber using the same model. The output of MatLab-like area variation of single chamber and inlet and outlet port was used as input for this model as described by Hussain *et al.*[13]. In this model, it is assumed that the fluid is incompressible and completely fills in the chamber. The volume of each chamber is simulated using a hydraulic piston model where area variation and rotor thickness are taken as inputs. Finally, all five chambers are connected with a phase difference of 90 degree. Theoretical flow rate is estimated by multiplying the variation of volume with the angular velocity of the inner rotor.

2. 3D CFD ANALYSIS

The commercial computational fluid dynamics (CFD) tool Ansys Fluent was used to simulate the operation of Gerotor and to predict the performance of the pump. The fluid volumes included the micron-scale leakage gaps (axial and radial). In Solver, the boundary conditions and fluid properties were prescribed. Setting the boundary conditions simulates the operation of a real test, in that speed and pressure boundaries, are specified. The fluid properties are dictated by setting the density and viscosity of the fluid. The computational domain along with the inlet and exit plane of the Gerotor pump is shown in Fig. 2. A transient simulation was carried out with a time step calculated based on the 0.25 degree rotation of the inner rotor. Time step 0.25 was selected based on simulation results for three values of the increment of shaft angle (0.5 deg, 0.25 deg, and 0.1deg). Not much (less than 0.2 per cent) flow rate variation was found from 0.25 deg to 0.1 deg. Hence 0.25 deg was selected to save computational time and maintain accuracy at the same time.

Table 1. Geometrical parameter

Geometrical parameter	Value in mm
Outer Lobe radius (S)	17.6
Eccentricity (e)	3.5
The radius of a circle to complete external gear (G)	21.8
Number of outer lobes(n)	5
Distance of the centers of circular arc from center O_1	31.6
Thickness of rotor	7

CFD domain of the pump flow passageways is shown in Fig. 2. To perform a CFD simulation for a Gerotor using Fluent, the deforming fluid volume is identified as the region between the Gerotor gears. This fluid region is known as the Gerotor core (Fig. 3) and the entire fluid volume is decomposed into moving and deforming volumes. Approximately three million elements were used after the grid-independent study. k-ε turbulence model is used for analysis. Apart from tip-to-tip clearance i.e., the clearance that exists between the inner and outer rotor, axial and radial leakages are included, this arises due to clearance that exists between static and moving parts. Clearance between the shaft and inner rotor is not considered in the present work.

Unsteady single-phase CFD analysis of flow through a gerotor oil pump was carried out at various speed and outlet pressure conditions. Oil inlet pressure and temperature were maintained constant at 100 kPa and 100 °C respectively.

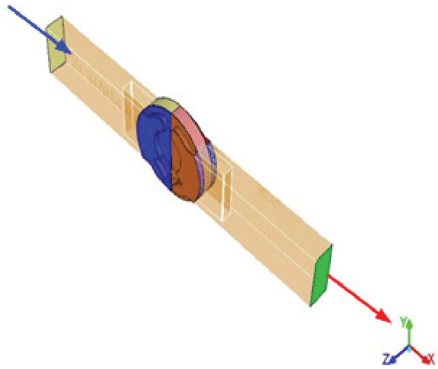

Figure 2. CFD domain.

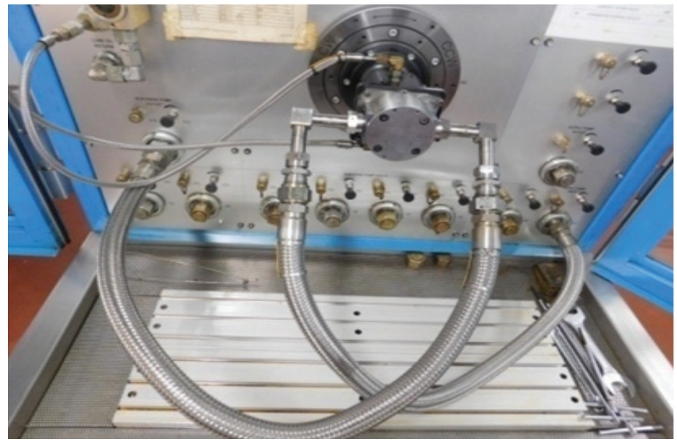

Figure 4. Assembled gerotor pump in the test rig.

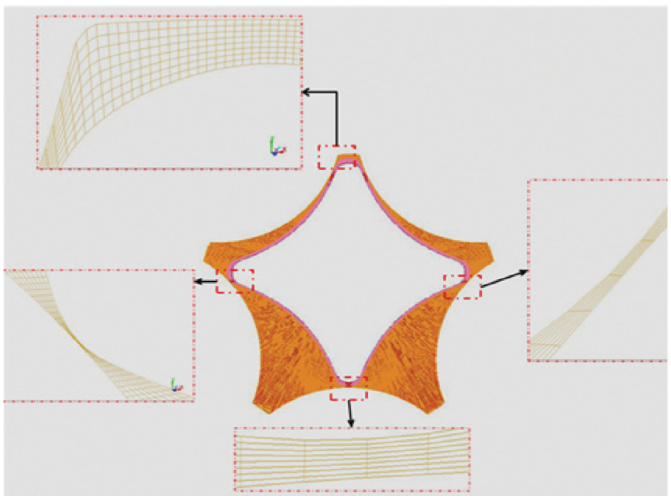

Figure 3. Gerotor core volumes.

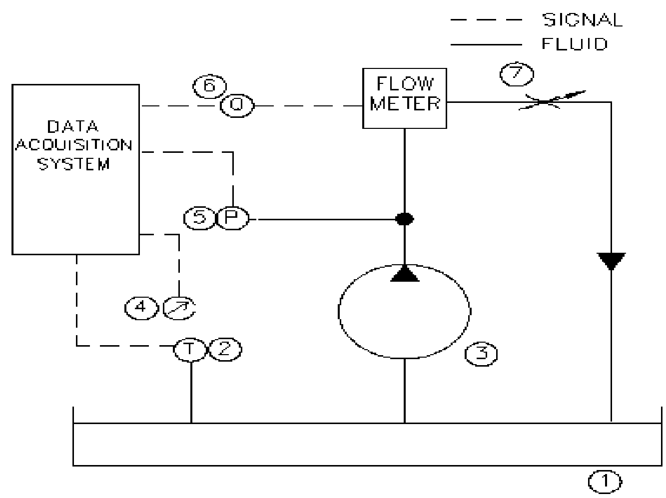

Fig. 5. Layout of the experimental setup.

3. EXPERIMENTAL SETUP

The designed gerotor pump was manufactured and assembled in a test rig as shown in Fig. 4. A schematic diagram of the test rig is shown in Fig. 5.

Oil is drawn by test unit (oil pump) (3) from a tank (1) and delivered to a turbine flow meter (6), control valve (7) and it is returned to the tank. In the test, a bench heater is used to heat oil (not shown in Fig. 5) and a thermocouple (2) is used for temperature measurement inside the tank. Discharge pressure at the pump exit is measured using a pressure transducer (5) and speed of rotation is measured by an eddy current-based sensor (4). A variable frequency electric motor (not shown in Fig. 5) is used to drive the test unit (oil pump); a pressure control valve (7) is used to set the outlet pressure in the delivery line. Lubrication oil used was as per MIL-PRF-23699F.

A brief description of instrumentation used in the experimental setup is given:

- Turbine type flow with the accuracy of 0.5 per cent
- Pressure transducer: Diaphragm strain gage based measurement principle with the accuracy of 0.1 per cent
- Thermocouple: K-type with the accuracy of ± 1.5 °C.

4. RESULTS AND DISCUSSION

Tests were performed over a range of pump speeds while maintaining constant outlet pressure and oil inlet temperature. Tests were repeated by varying outlet pressure and inlet temperature while maintaining constant inlet pressure of 100 kPa.

A comparison has been made between experimental test results and simulation results and is shown in Fig. 6. Here, Flow rate was normalised with pump capacity at maximum speed.It is observed that simulated flow rate values closely matched the experimental results. CFD model predicts the flow rate at maximum speed 1.2 per cent higher than experimental at outlet pressures of 200 kPa and 6.5 per cent higher than the experimental result when the pump was operating at 400 kPa.

Volumetric efficiency was estimated at the different operating conditions and compared with experimental results. Volumetric efficiency is calculated by the ratio of the volume flow rate from CFD or experimental result on the theoretical flow rate computed from the AMESim model. Figure 7 shows the volumetric efficiency behaviour at different outlet pressure and pump speed while oil temperature was kept constant (100 °C). Since the present study is focused on the supply pump of the lubrication system, the oil temperature was limited to 100 °C. It was found that prediction from the simulation model is closely matching with experimental results. It is found that CFD predicted volumetric efficiency is reduced by about 1 per cent when pump outlet pressure increased to 400 kPa from 200 kPa. This is due to the increase of internal leakage of pump which depends on the pressure difference between inlet and outlet port. Figure 7 shows that CFD predicted volumetric efficiency at maximum pump speed is higher by 1.8 per cent and 4.2 per cent than experimental volumetric efficiency when the pump is at outlet pressures of 200 kPa and 400 kPa respectively. While increasing outlet pressure from 200 kPa to 400 kPa, the pressure difference is increased by three times (100 kPa to 300 kPa).

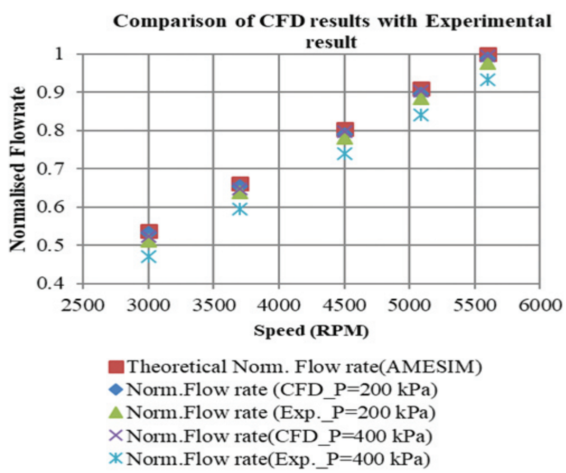

Figure 6. Comparison of Flow rate between simulation result with the experimental result.

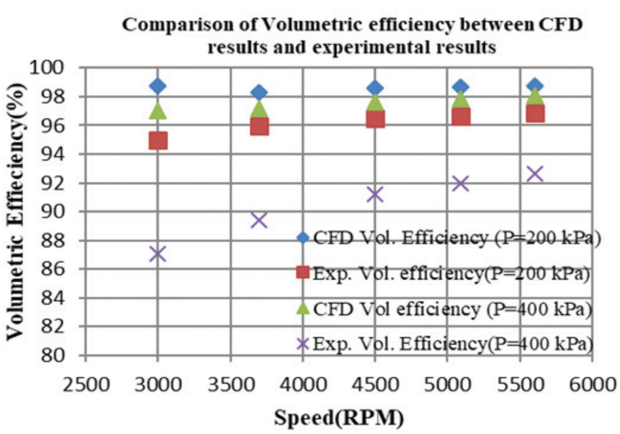

Figure 7. Comparison of volumetric efficiency between simulation result with the experimental result.

In this study, leakage flow through the clearance between the shaft and inner rotor is not considered which is proportional to the pressure difference between delivery and suction line. This could be the reason that CFD prediction is quite closer to the experimental value at outlet pressure 200 kPa compare to outlet pressure at 400 kPa.

Further similar experiments were performed at lower oil temperature (40 °C) and flow rates were measured at different speeds and outlet pressures. Oil viscosity at 40 °C is approximately five times higher than viscosity at 100 °C. Figure 8 shows the variation of estimated volumetric efficiency for pump speed at two different oil temperatures and outlet pressures.

It was observed that volumetric efficiency gets increased at lower temperatures by 1.7 per cent and 5.3 per cent at outlet pressure 200 kPa and 400 kPa respectively. This is due to the reduction of internal leakage since oil viscosity is more at oil lower temperatures. It was found that volumetric efficiency gets decreased by 5 per cent at maximum pump speed when outlet pressure increased from 200 kPa to 400 kPa while maintaining constant oil temperature 100 °C. Similarly, volumetric efficiency decreases by 2.2 per cent at lower oil temperatures.

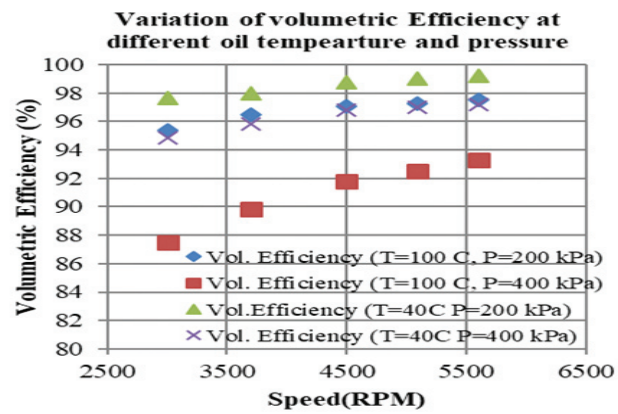

Figure 8. Volumetric efficiency at various operating conditions.

5. CONCLUSION

This paper presents a flow analysis and parametric evaluation of a lubricating oil pump. Unsteady single-phase CFD analysis of flow through a Gerotor oil pump was carried out at various design conditions. The results obtained by these analyses were compared with the experimental values and results predicted by the simulation model show agreement with experimental values. A further effect of the operating condition like pump speed, outlet pressure, and oil temperature on pump performance has been studied. It was found that the contribution of outlet pressure to the pump volumetric efficiency was significant.

Future studies will be focused on modeling shaft leakage flow to get closer results from CFD simulation. This methodology can be extended for a flow analysis of the multistage Gerotor pump.

Thus, this methodology enables the faster design of the pump, and the simulation technique adopted is found useful for flow control enabling quicker modification of the gerotor pump design of an aero engine.

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In the current study, he has extended his guidance to the main author for simulation studies, analysis, and final scrutiny of the paper.