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# Modelling of Cavitation and Aeration Effects on a Gerotor Pump of a Lubricating System in Automobiles

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**ABSTRACT:**

*In an internal combustion engine, lubrication system acts as an auxiliary system, proper operation of it is essential for optimal performance of an engine. Mostly, positive displacement pumps are used for pumping the lubricating oil at constant flow rate at a given speed. In that, Gerotor pump is a commonly used pump. Cavitation affects the volumetric efficiency of the pump, which in turn influenced by operating conditions like speed of the pump, suction pressure etc. The current study using 3D pump flow simulation tool, Simerics-MP+ revealed that the cavitation bubbles form near the teeth of the rotors on the suction side. The location at which the bubbles expand, and collapse are correctly predicted at two different configurations and its effect on the performance is validated with the experimental data.*

**KEYWORDS:**

*Gerotor pump; Cavitation; Vapour mass fraction; Total gas mass fraction; Volumetric efficiency*

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## 1. Introduction

The lubrication system is vital systems in an internal combustion engine that deliver lubricant oil to different moving components like bearings, piston and even cools the piston during the combustion process. The lubricant oil acts as a working fluid for several other units such as hydraulic valves tappets, actuation systems, belts and driving chains. For all these purposes, positive displacement pumps are used to deliver constant flow rate at specific speed. Gerotor is a rotary positive displacement pump used in the lubrication systems. Its efficiency at high speed and low suction pressures may drop up to 30% [2]. Gerotor pump is a positive displacement pumping unit consisting of an inner rotor and an outer rotor. The outer rotor has one extra tooth than the number of teeth of inner rotor and has its centerline positioned at a fixed eccentricity from the centerline of the inner rotor and shaft.

Although, Gerotor pumps come in a variety of geometric configurations, materials and sizes, all Gerotor sets share the basic principle of having conjugate-generated tooth profiles which provide continuous fluid-tight sealing during operation. As the rotors rotate about their respective axes, fluid is drawn into the enlarging chamber to a maximum volume. As the rotation continues, chamber volume decreases, forcing fluid out of the chamber. The process occurs constantly for each chamber, providing a smooth pumping action [3]. When the pressure goes below the saturation pressure of the working fluid, there is a high impact on the overall performance due to cavitation. Dario et al [4] observed pump cavities at low suction pressure and delivery pressure. Dario et al [5] induced cavitations conditions and observed a constant flow rate at different speeds in the cavitation regime. Altare et al [6] conducted 3-D simulations and validated with the experimental data at different cavitation conditions.

Simulation of Gerotor is complex due to change in volumes between the teeth with the rotation of inner and outer rotor. The generation of mesh to simulate a 3-D model for intricate teeth meshing and micron sized gaps is done by H. Ding et al [7] in Simerics-MP+ [1]. The simulation model can capture the complicated motion of the Gerotor by using a transient mesh and able to capture the loss by using a cavitation model. The simulation model can predict gas mass fraction relative to the rotation of rotor. The cavitation model in Simerics-MP+ is developed based on the mathematical model of cavitations by Singhal et al [8].

## 2. Model setup

A Gerotor CAD model is constructed based on the geometric data provided in Altare et al [6]. The rotor volume is constructed for a capacity of 19.8 cc/rev. The geometric parameters used to build a rotor fluid volume are given in Table 1. The rotor profile (Fig. 1) is created using the above geometric data and is extruded into a 3D volume by the value of rotor thickness. A clearance of 45 microns is created and maintained between the inner rotor and outer rotor. The inlet and outlet ports (shown in Fig. 2 and Fig. 3) are created on the rotors with an inner radius - 18.1 mm, outer radius – 27.75 mm and angle difference – 138º. The created rotor surfaces are meshed in Simerics-MP+ [1]. The axial clearance gaps as suggested in [6] are included. The template feature in

Simerics-MP+ generates moving grid for every rotational position of the rotors. Mesh generated at an angular position is shown in Fig. 4. Side leakage gaps (Fig. 5) are considered in the model to accurately predict performance loss due to leakages. The total mesh count is 399182 cells. Since the gear rotation is important to capture asymmetric flow field and cavitations bubbles, a transient simulation is carried out for specific rpm and for specified pressures at the boundaries.

**Table 1: Gerotor pump geometrical information**

| Parameter | Value |
|---|---|
| Eccentricity | 3 mm |
| Max outer diameter | 62.1 mm |
| Radius outer lobes | 12 mm |
| Radius inner rotor | 17.34 mm |
| Rotor thickness | 25 mm |
| Inner rotor teeth | 6 |
| Outer rotor teeth | 7 |

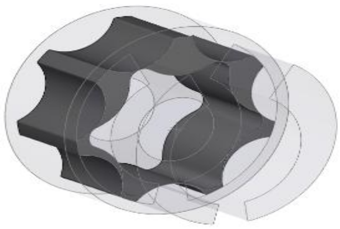

**Fig. 1: Rotor**

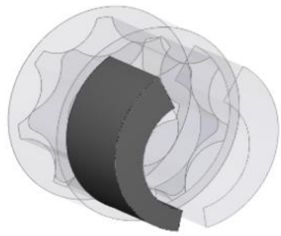

**Fig. 2: Inlet**

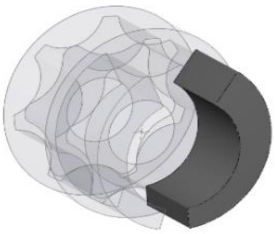

**Fig. 3: Outlet**

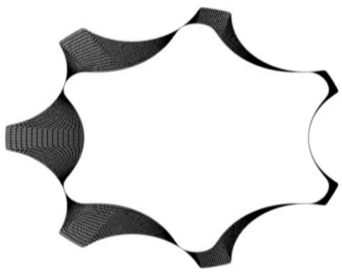

**Fig. 4: Rotor volume cross section**

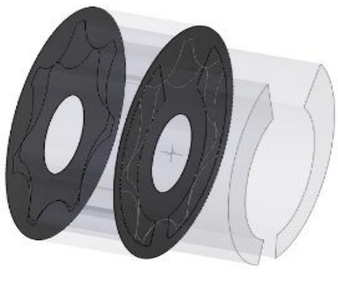

**Fig. 5: Axial gaps**

The considered lubricant is SAE grade 5W30. The fluid viscosity and density are taken at 40º C. Equilibrium Dissolve Gas Model is used for capturing cavitations. This cavitations model accounts phase change of the lubricant and the effect of non-condensable gases both in dissolved and free form. Since the non-condensable gas in this simulation is air, the content of air presents in the lubricant is given in terms of dissolved gas mass fraction as 3e-05 at 300 K temperature, which corresponds to 2% (by volume).

## 3. Model validation

The experimental data is taken from Altare et al [4]. The experimental setup considered oil sump, pipe with two restrictors which feed oil to the Gerotor pump as shown in Fig. 6. In the current study, numerical investigation is made for configurations - without activating the restrictors and activating the two restrictors. The suction pressure drops while the oil passes through the two restrictors. So, the following two configurations are simulated by considering different suction pressures:

- First configuration is simulated by considering the inlet pressure of 1 bar and outlet pressure of 4 bars.
- Second configuration is simulated by considering the inlet pressure of 0.7 bars and outlet pressure of 4 bars.

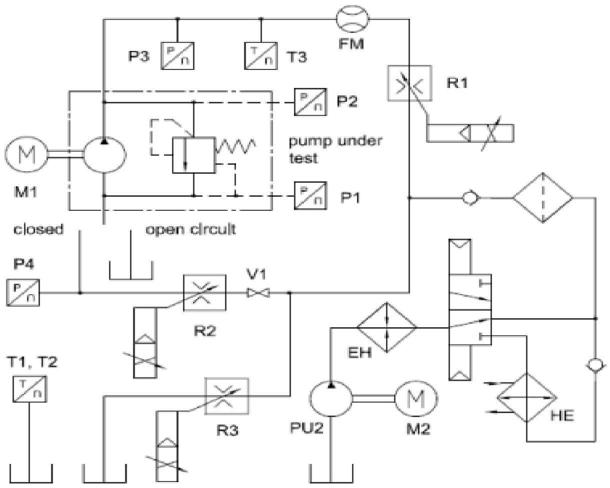


**Fig. 6: Hydraulic circuit**

The two configurations are run at different speeds. The first configuration is simulated without considering the cavitations phenomenon. The second configuration is simulated with cavitations using Equilibrium Dissolve Gas Mass Model. The volumetric flow rate with change in RPM for the first configuration is shown in Fig. 7. Every test point is simulated for at least 5 revolutions to ensure the solution has reached quasi-steady state. The flow rate should theoretically increase with the increase of RPM. As shown in Fig. 7, the experimental flow rate linearly increases with RPM up to 4500 RPM and the slope drops because of cavitations after 4500 RPM. RPM in the simulation, as cavitations is not considered, the flow rate is over-predicted by 5% at 5000 RPM. The good comparison with the experimental data up to 4500 RPM signifies that the geometry and the leakage gaps considered are correct. The performance curve for configuration 2 is shown in Fig. 8. As mentioned earlier, in this configuration, inlet pressure is reduced to 0.7 bars to mimic the resistance due to the two resistors. As shown, the simulated flow rates compare well with the experimental data both in non-cavitations (up to 3000 RPM) and cavitations zones (after 3000 RPM). As expected, the predicted flow rates flatten with RPM during cavitations.

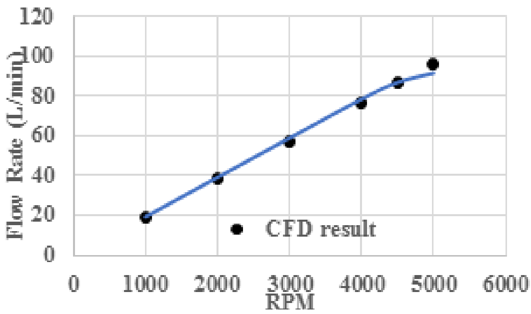


**Fig. 7: Volumetric flow rate vs. RPM (configuration 1)**

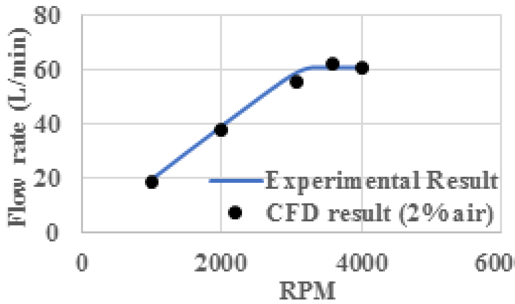


**Fig. 8: Volumetric flow rate vs. RPM (configuration 2)**

## 4. Results and analysis

Pressure contours of configuration 2 at different time instances of one tooth rotation angle at 4000 RPM are shown in Fig. 9. As the rotors rotate in counter-clockwise direction, the volume enclosed between the rotors expands near the inlet port and compresses in the outlet port region. As shown in Fig. 9(a), for instance, the lubricating oil between expanding teeth 2 and 3 experiences pressure below 1 bar. The same volume during compression, experiences pressure in the order of 5 bars (shown in Fig. 9(b)). The rapid expansion and compression of the volumes drive dissolved gas to be released and absorbed from the base lubricant oil. This phenomenon is called as aeration. On the other hand, the chance of cavitations due to evaporation of the lubricating oil is minimal as the pressure rarely falls below the saturation pressure of the lubricating oil. The cavitations phenomenon is more predominant at higher speeds and low inlet pressures as the pressure further falls during the suction at the inlet port region. The cavitations affect the performance of the pump.

The important regions of the pump are highlighted in Fig. 10, which are referred in the following sections. The transient evolution of vapour bubbles between teeth 1 and 2 at different time instances during one tooth rotation is tracked in Fig. 11 with iso-surface of 0.1 for vapour volume fraction. As shown, small vapour bubbles form near the tip of the teeth and start to disappear by the time the teeth gap reaches near the outlet port region (Figs. 11(b) and (c)), where the pressure starts increasing. As the vapour bubbles formed are small to cause obstruction to the flow, the volumetric efficiency of the pump is un-affected.

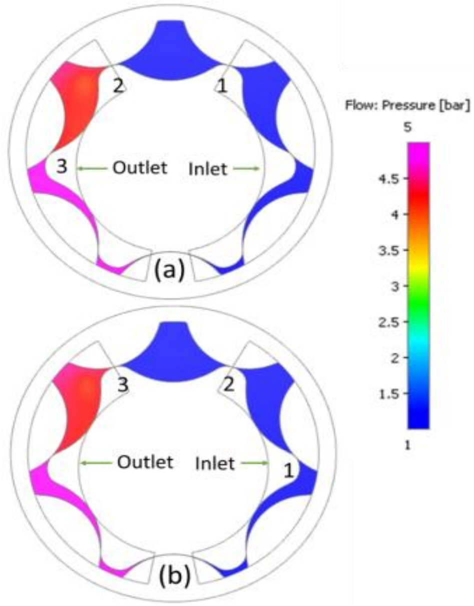


**Fig. 9: Pressure contours**

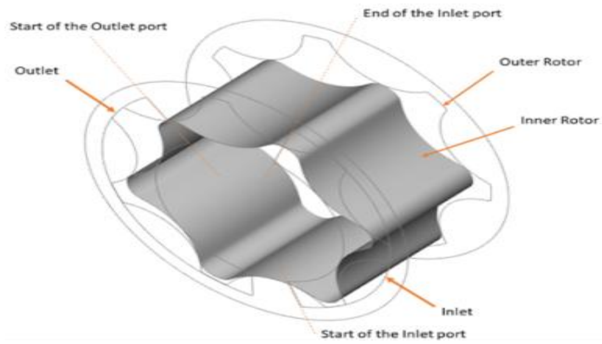


**Fig. 10: Gerotor nomenclature**

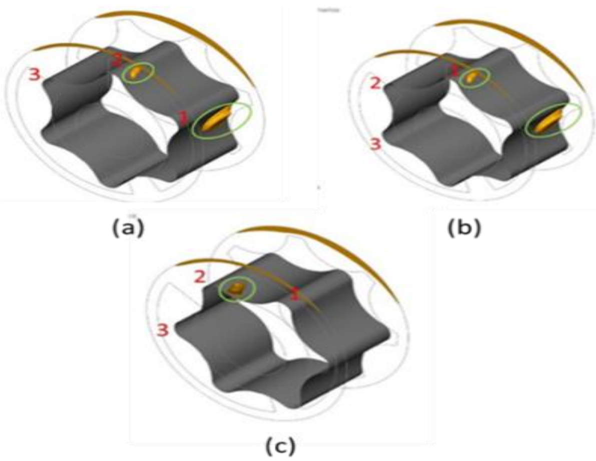


**Fig. 11: Iso-fractions of 0.1 Vapour volume fractions**

Gas bubbles evolution is understood with the help of iso-surface of total gas volume fraction in Fig. 12. Total gas volume fraction is the sum of volume fractions of vapour and gas. In that, gas fraction is a major component compared to the negligible vapour volume fraction. The transient variation of the iso-surface of 0.5 is analysed in Fig. 12 for one tooth rotation. As shown, in the low-pressure region of the inlet port, the big bubble as expected always exists and starts disappearing as the pressure rises to the range of 5 bar when the volume between the teeth 2 and 3 moves to the outlet port region. The big bubble formed in the inlet port region blocks the flow and affects the volumetric efficiency of the pump. This is evident in the performance plot shown in Fig. 8.

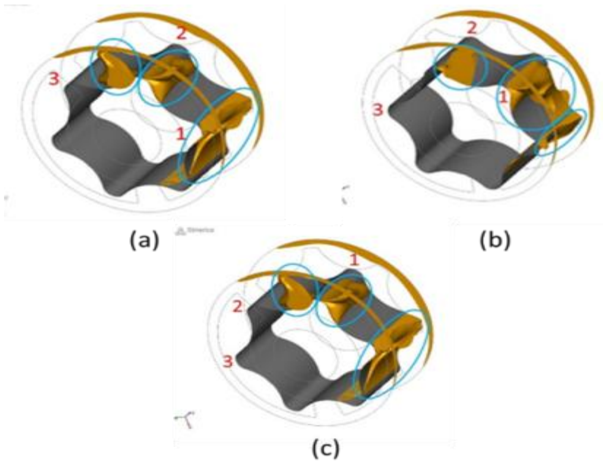


**Fig. 12: Iso-fractions of 0.5 total gas volume fraction**

## 5. Conclusion

The configuration 2 has shown severe cavitations at speeds higher than 3000 RPM. The cavitations effect is less seen in configuration 1 as the inlet pressure of 1 bar is high enough to avoid cavitations even at higher speeds. The performance of the pump is validated for both the configurations. Further analysis revealed that it is aeration effect of gas rather than the cavitations due to vapour formation of the lubricant oil. The present work has also captured the flatten flow rate during the severe cavitations regime at high speeds in configuration 2.

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