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A Review on Development of Design methodology of variable displacement oil pump for I.C. Engines.

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ABSTRACT

Automotive lubrication system has been studied for long time, looking for improving its efficiency and reduce power consumption. In this context ,oil pump plays an important role since most of the systems are made of constant flow pumps, with relief valve to make a recirculation of the excess oil, which contributes to loss. This project aims at experimental approach for the determination and analysis of the pressure distribution and lumped parameters numerical modelling of a variable displacement vane pump for high speed internal combustion engine. The study will present geometric, kinematic and fluid-dynamic modelling of variable displacement vane pumps for low pressure applications in internal combustion engines lubrication. All these fundamental aspects will be integrated in a simulation environment and form the core of a design tool leading to the assessment of performance, critical issues, related influences and possible solutions in a well grounded engineering support to decision. An extended test campaign can be performed on the pump to characterize its operational behaviour. Rotational speeds from the idling regime to the maximum sustainable regime will be tested by varying the hydraulic circuit load: the results of the pressure field can be analysed together with a detailed description of the oil physical behaviour into the pump.

Keywords- **Oil Pump for I.C engine, Variable displacement oil pump,Vane pump**

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I. INTRODUCTION

The primary purpose of oil pump in an internal combustion engine is lubrication. It circulates engine oil under pressure to the rotating bearings, the sliding pistons and the camshaft of the engine. This lubricates the bearings and assists in cooling the engine. The oiling system addresses the need to properly lubricate an engine when it is running. Properly lubricating an engine not only reduces friction between moving parts but is also the main method by which heat is removed from pistons, bearings, and shafts. Failing to properly lubricate an engine will result in engine. Due to inherent design of gerotor pump, the oil flow supplied to the engine is fixed in nature. However, the engine flow rate requirement is less as compared to that of gerotor supplies. Hence, there is a need for variable delivery pumps, the active control matches the oil flow and pressure that the engine needs, eliminating excess oil flow, significantly reducing the parasitic load on the engine crankshaft, and ultimately saving fuel. In variable delivery pumps, changing the displacement volume controls the flow rate. Vane-pump designs have hydraulic controls and actuators that move the pump housing and vary the eccentricity of the rotor. David Staley, Bryan Pryor [1] had worked on adaptation of variable displacement vane pump to engine lube oil application and derived the equation for the displacement considerations useful for calculating the displacement of the pump at different speeds and eccentricities. They also explained the need of variable delivery oil pump and its advantages. S. Loganathan, S. Govindarajan [2] worked on design and development of vane type variable flow oil pump for automotive application and arrived at mathematical modeling of the vane pump for the flow rate calculation. The theoretical results are compared with the experimental results in terms of pressure plot, flow rate plot and power plot.Joao Meira [3] worked on strategies for energy savings with use of constant and variable oil pump systems and described the actual pumping systems in terms of design and application and compared them with new variable pumps. Use of pressure relief valves and the mechanism of oil recirculation are clearly described.

The typical vane type pump with maximum and minimum clearance is explained with help of schematic diagrams. FumihikoTayoda, Yukimori [4] worked on design and analysis of vane type oil pump for automotive application and the vane pump with five vanes is designed and FEA analysis is carried out on the pump components to find out the maximum stress developed in the pump. The types of loads and the forces applied on the pump are discussed. S. Mancho [5] worked on the modeling and simulation of variable displacement vane pumps for IC Engine application, presents the geometric, kinetic, and fluid dynamic modeling of variable displacement vane pumps for low pressure applications in internal combustion engines lubrication. All the fundamental aspects are integrated in the simulation environment and form the core of a design tool leading to assessment of performance, critical issues related influence and possible solution is explained.

De Ming Wang [6] worked on numerical modeling of vane oil pump with variable displacement and derived the mathematical model for the variable delivery oil pump which contains the governing equations for the fluids, dynamic equation for cam ring and a case study for mesh generation for the oil pump using Pumpkins software.

II. CONSTRUCTION AND WORKING OF VANE PUMP

The positive displacement vane pump has a rotor and stator with their centers at an offset distance (eccentricity). The change in the eccentricity changes the volume within the pump so that the flow rate can also be varied. This can be achieved with the help of a spring which contracts and expands with the change in the pressure. The theoretical results with the mathematical modeling for the calculation of flow rate and torque are arrived and they are compared with the target flow rate and also with the conventional fixed displacement pump.

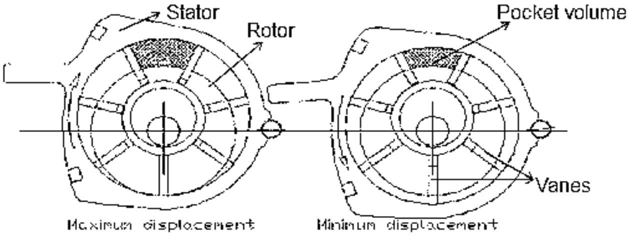

Figure a: Variable delivery oil pumps at maximum (left) and minimum (right) displacements

The Figure a explains in brief how the flow rate varies with the change in the eccentricity; the change in eccentricity is directly proportional to the displacement of the pump which in turn affects the flow rate.

Figure b; explains the construction of a variable delivery oil pump in detail and its major parts.

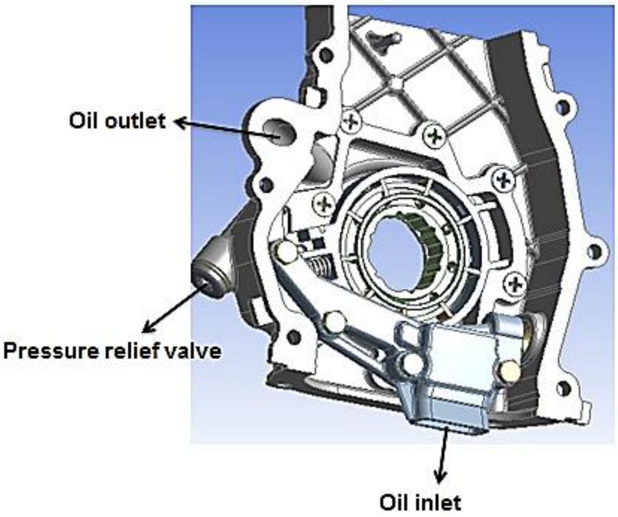

Figure b; Variable delivery oil pump

III. PUMP COMPONENTS:

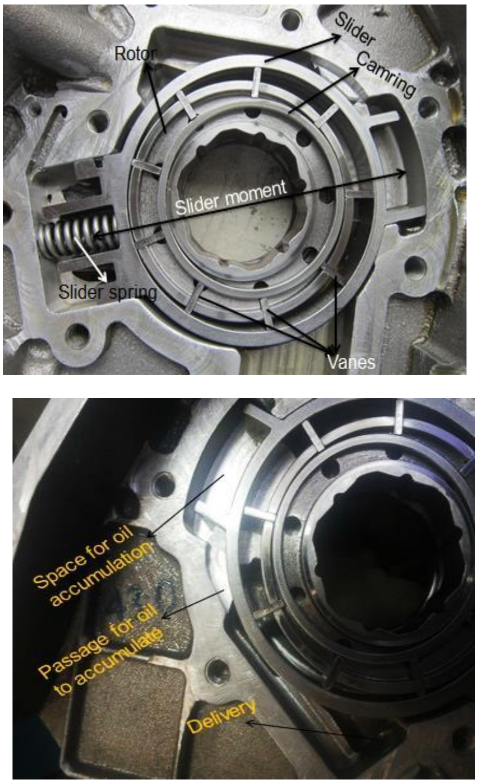

Figure c: Construction of variable delivery oil pump

IV.PARAMETRIC STUDY

It is found that the critical parameter that affect the flow rate is the design and dimensions of vane, so we consider the different dimensions of the vane to vary the flow rate; in order to vary the flow rate we consider vane thickness, no. of vanes, vane width and vane length as the critical parameters of the pump assembly and calculate the flow rate at critical power and torque points and arrive at a correlation.

Vane is the most important part of the pump assembly; the dimensions of the vane are the critical parameters for the pump design to achieve the required engine oil flow rate. The vanes are placed in the vane slits provided on the rotor and they are guided by the camrings one above the rotor and one below the rotor to move in and out.

1. VANE WIDTH:

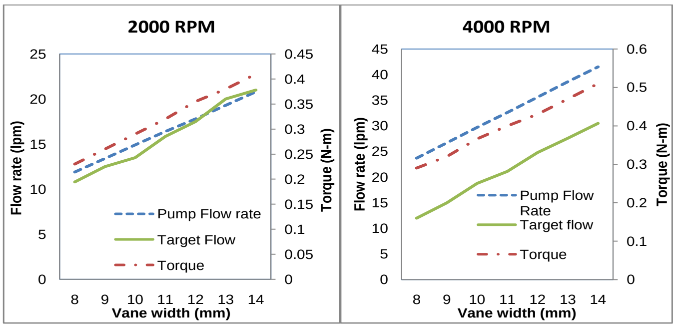

Figure d : Comparison of flow rate and torque with target flow with respect to vane width

Figure d; shows the correlation between vane width, flow rate and torque. It can be observed that. As the vane width increases the flow rate is also increasing. Hence, there is a positive correlation between vane width and flow rate. Similar trend is also observed for torque. The oil flow rate increases by 11% at rated power and 10% at rated torque point at the optimum vane width of 11 mm.

2. NUMBER OF VANES:

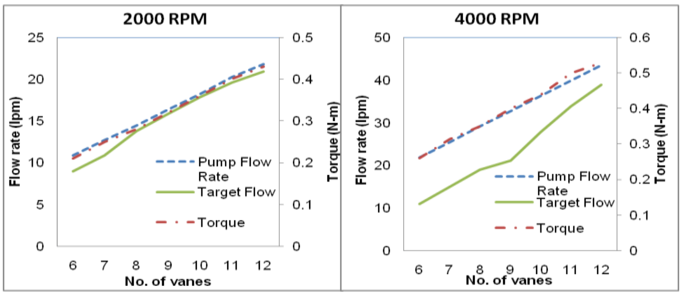

Figure E : Comparison of flow rate and torque with target flow with respect to no. of vanes

From Figure: E, the correlation between the number of vanes, flow rate and torque can be observed. With the increase in number of vanes the flow rate is increasing with increasing torque. The flow rate increases by 14% at rated power and 12.8% at rated torque point for the optimized pump having 9 vanes.

3. VANE LENGTH:

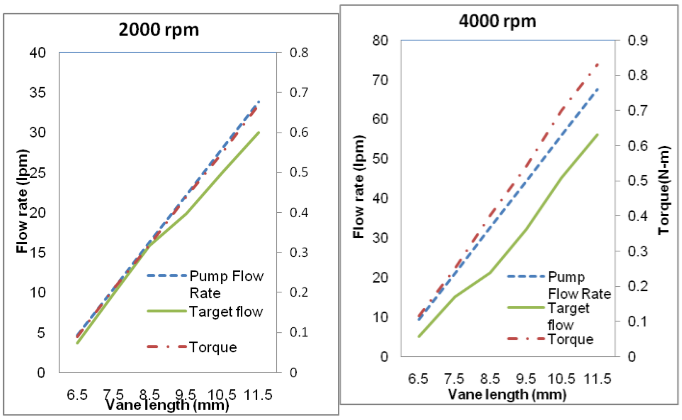

Figure F: Comparison of flow rate and torque with target flow with respect to vane length

From the figure F, the correlation between vane length, flow rate and torque can be observed. As the van length increase the flow rate is increasing with increasing torque.

Hence there is a positive correlation between vane length and flow rate. The flow rate increases by 55% at rated power point and 56% at rated torque point at the optimum vane length of 8.5mm.

4. VANE THICKNESS:

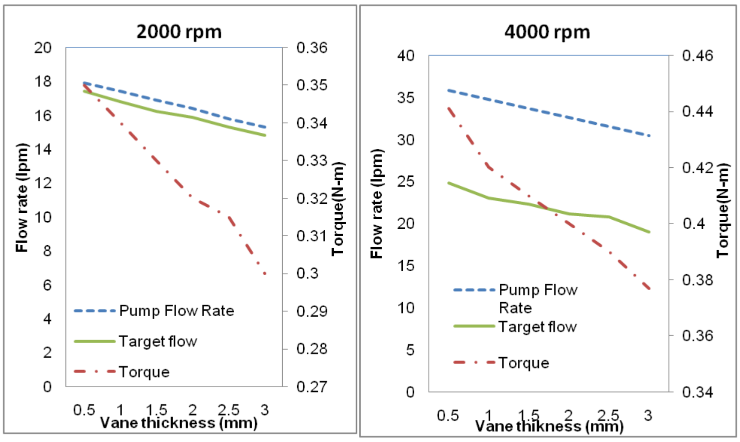

Figure G: Comparison of flow rate and torque with target flow with respect to vane thickness

From Figure G, the correlation between the vane thickness, flow rate and torque can be observed. As the vane thickness is increasing the flow rate is decreasing with decreasing torque. Hence there is a negative correlation between vane thickness and flow rate the similar trend is observed for torque. It can be observed that for every 0.5mm increase in vane thickness, the flow rate decreases by 3% at rated power and 2.5% at torque point at the optimum vane thickness of 2mm.

VANE TERMINOLOGY

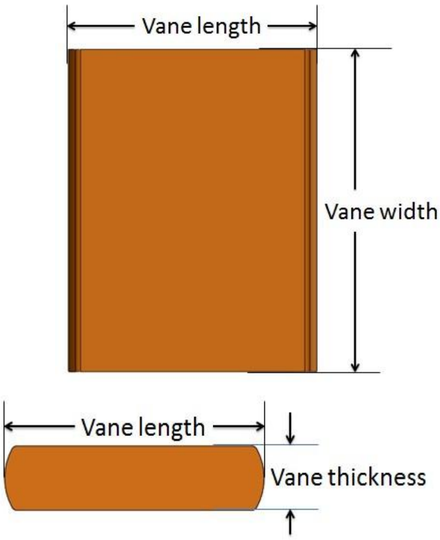

Figure 4.1: Vane

I. The *vane width* or rotor thickness is constrained with engine mounting face in such case the vane width or rotor thickness should not exceed the engine mounting face here we consider the space available for vane or rotor has a maximum thickness of 14mm.

II. The *no. of vanes* or adjacent vane angle shall be selected based upon space availability to place angularly to meet the target flow requirement there we selected typically vane angle of 40^0 no. of vanes as 9 and studied for vane angle ranging from 30^0 to 60^0 and number of vanes 12 to 6 respectively.

III. The constraint for *vane length* is the space available for the vane to move in and out from the rotor towards the camring and slider.

IV. *Vane thickness* is constrained by the angle between two adjacent vanes such that the vanes do not overlap each other and it has to meet the target flow and torque requirement.

5. TORQUE:

The torque required to drive the variable delivery oil pump can be estimated from the following equation,

$$\text{Torque(N-m)}=\frac{Pressure\,(Mpa)*Flow\,rate\,(LPM)*159}{RPM} \quad \text{Eq.: 1}$$

From the Eq.: 1 it is apparent that torque required to drive the pump is directly proportional to the engine oil delivery pressures. As the engine oil delivery pressure increases the torque required also increases. From this equation the torque required to drive the pump can be calculated at different speeds of the pump in terms of N-m.

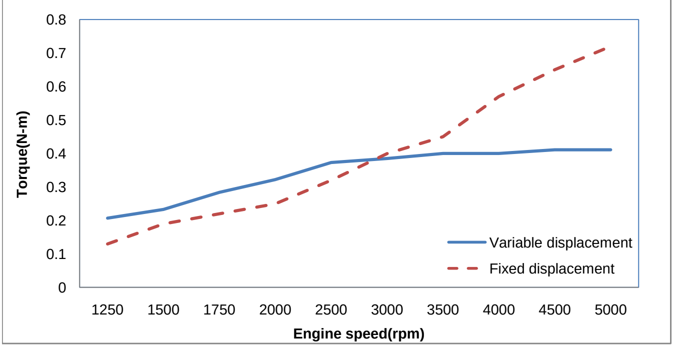

Figure:H; Comparison of fixed and variable displacement torque consumption for different engine speeds

Figure 'H' shows the comparison of required torque for the fixed and variable delivery oil pump. The torque required to drive the fixed displacement pump at rated torque point (2000 rpm) is lower when compared to the variable displacement pump by 21.8%. At rated power point (4000 rpm) the torque required by the fixed displacement pump is 30% higher when compared with variable displacement pump.

6. FLOW RATE:

The flow rate of variable delivery oil pump can be estimated by using the following equation,

$$\text{Pump flow (lpm)} = \frac{\text{RPM} * \text{Pump Displacement}\,(\text{cm}^3)}{1000} \quad \text{Eq.: 2}$$

From the Eq.: 2 it is clearly known that the engine oil flow rate is directly proportional to the displacement of the pump. In a variable delivery oil pump due to is constructions and use of a spring the displacement of the pump continuously changes with change in engine oil delivery pressure and working speeds

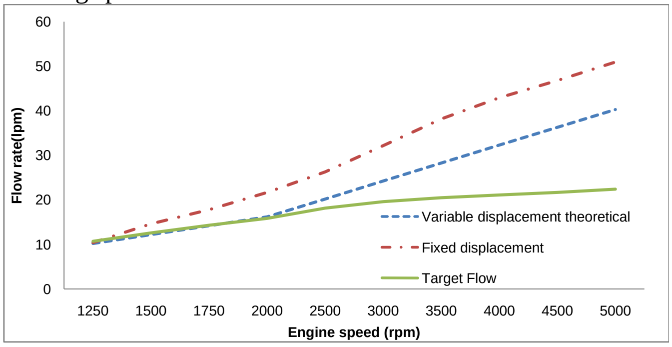

Figure: I. Comparison of fixed and variable delivery flow rates for different engine speeds

Figure 'I' shows the comparison of flow rate for fixed and variable displacement pumps for different engine speeds. It can be observed that the variable displacement pump oil flow rate meets the target at rated torque (2000 rpm) whereas, the fixed displacement pump delivers 32% of excess oil. At rated speed (4000 rpm), the variable displacement pump delivers 45% of excess oil whereas fixed displacement pump delivers 57.6% of excess oil. The reduction in flow is about 12%, which will be beneficial to reduce the power consumption. By including the pressure relief system, the flow rate can be further reduced closer to the target flow

7. PUMP DISPLACEMENT CONSIDERATIONS:

As with most positive displacement pumps, the vane pump's displacement is a function of its eccentricity which is defined as the positional difference in rotors center with respect to the slider's center.

In general the pumps displacement is approximated by; by David Staley et al. (2007)

$$D = 2\varepsilon wn\left(2r\sin\left(\frac{\theta}{2}\right) - t\cos\left(\frac{\theta}{2}\right)\right) \quad \text{Eq.: 3}$$

Where D= Displacement (mm^3)

ε= Eccentricity (mm)

w= vane width (mm)

n= number of vanes (nos)

r= camring inner radius (mm)

t= vane thickness (mm)

θ= angular vane spacing (deg)

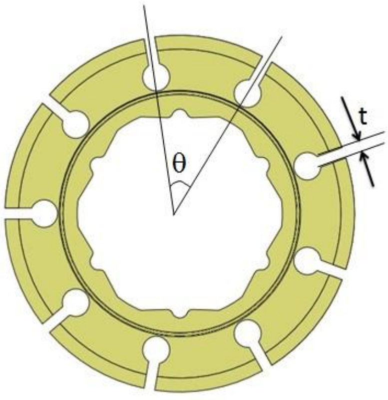

Figure: J ;Vane thickness (t) and angle between two adjacent vanes (θ)

From the above Eq.:3 it is apparent that pump displacement is directly proportional to eccentricity, which explains the fundamental behavior of pumps operation.

For a variable delivery oil pump the eccentricity (ε) depends on the pressure exerted on the spring and the displacement of the slider. Hence, displacement of the slider spring is calculated as follows;

According to Hooke's law we know that $F = -kx$ Eq.:4

Where, F is Force (N)

k= spring stiffness (N/mm)

x= spring displacement (mm)

The negative sign indicates the direction of displacement is in the opposite direction.

V. CONCLUSION

A conclusion section is recommended as it helps to fulfil requirements of variable displacement vane type oil pump by calculating vane parameters, pump displacement, flow rate, torque. Also explains the scope of the work presented in the paper.

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