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Strategies for energy savings with use of constant and variable oil pump systems

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ABSTRACT

Automotive lubrication systems have been studied for long time, looking for improving its efficiency and reduce power consumption. On this context, the oil pump plays an important role, because most of the actual systems are made of constant flow pumps, with a relief valve to make a recirculation of the excess of flow, which is an important point of losses. On this paper we describe the actual pumping systems in terms of design and application and compare them with the new variable pumps.

INTRODUCTION

Oil pump is an engine component responsible to provide adequate lubrication on engine components like bearings and helps to keep them in an adequate working temperature. It is a component of engine that has not faced significant changes on the last 50 years, due to simplicity and robustness of construction and importance to engine performance and durability. As any other device it is a power consumer and has been studied for years to improve its efficiency.

Fig. 1 Shows a typical comparison between engine torque of a 1.0L engine at 50% load and oil pump draw torque [1]. The oil pump assembled is a gerotor type pump, direct driven by engine crankshaft. It can be observed that pump torque can reach up to 2,5% of engine torque . Reduction of this value by using different pump types or alterations on drive characteristics can represent important fuel savings and engine efficiency gains. The aim of this work is to evaluate torque and fuel savings on engine by changing the conventional gerotor pump by different concepts of pump and drive systems.

Speed rpm	Engine torque N.m	Pump torque N.m	Pump Representation %
1000	63	0,34	0,54
1500	73	0,59	0,81
2000	74	0,89	1,20
2500	78	1,09	1,40
3000	83	1,19	1,43
3500	80	1,28	1,60
4000	83	1,38	1,66
4500	85	1,5	1,76
5000	82	1,59	1,94
5500	78	1,67	2,14
6000	72	1,77	2,46

Fig.1. Typ.engine rated torque at 50% load x pump torque

OIL PUMP AND OIL PUMP SYSTEMS

There are various oil pump concepts being used in automotive engines. Each one has benefits and drawbacks to be observed. There are three the main concept variation present on current vehicles:

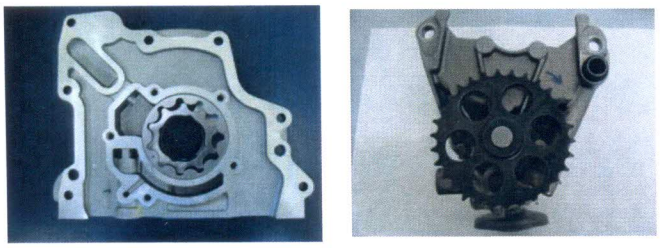
- Pump type (Fig.2)

- Pump location on engine (Fig.3)

- Pump displacement (constant or variable) (Fig.4)

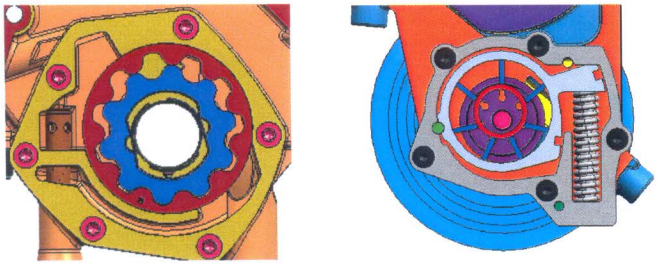
Gerotor Spur gear Vane type

Fig.2 . Different types of automotive oil pumps



Pump direct driven by crankshaft Pump driven by transmission system

Fig. 3. Pump location on the engine



Constant flow pump with relief valve Variable flow pump

Fig. 4 Fixed and variable pump displacement

For safety reasons, oil pumps are usually direct driven by engine crankshaft. In some cases where pump is located far from the crankshaft end, some kinds of transmission, normally by chain or gear are required.

Finally, in general oil pumps are pumps with constant flow and a relief valve. It makes design and manufacturing of oil pump easy and cheaper, but produces a excess of flow in most of working conditions, that is of course energy loss not desired.

The new variable systems are gaining space on the market by avoiding these losses contributing for production of more efficient engines. This will be the scope of this paper.

ENERGY LOSSES ON PUMPS

Oil pumps are sized to low speed and high temperature condition, which is the worst condition for the lubrication systems. By designing the oil pump to satisfy this condition, the pump became too big for other situations, producing a excess of flow that is usually managed by a relief valve. Fig. 5 shows comparison between typical 1.0L engine flow requirements and flow produced by oil pump [2].

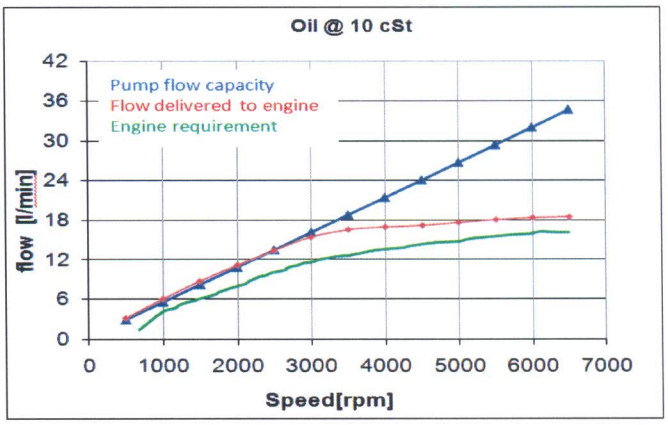


Fig.5 Typical oil flow demand and comparison with constant pump delivery.

In order to maximize efficiency of lubrication systems, pumps must be able to match engine oil demand as close as possible and with a minimum internal leakage and friction losses. A good practice is to use a pump with smallest diametral dimensions, once internal leakage and friction drag increase with diameter of pump rotating elements. This becomes more effective when pump is assembled out of crankshaft.

High pump speeds also reduce the pump efficiency, due to increasing of friction losses. Most of pumps assembled out of crankshaft uses a transmission ratio between engine and pump to use the benefit of reduction of pump speed. Fig.6 shows comparison of mechanical efficiency between a pump direct driven by crankshaft and a pump not direct driven by a crankshaft [3].

The use of relief valve is also a source of energy losses, because the excess of flow at high pump speed stays recirculating inside the pump does not making any useful work. Fig.7 shows a comparison of volumetric efficiency between a pump with relief valve and a variable pump without relief valve.

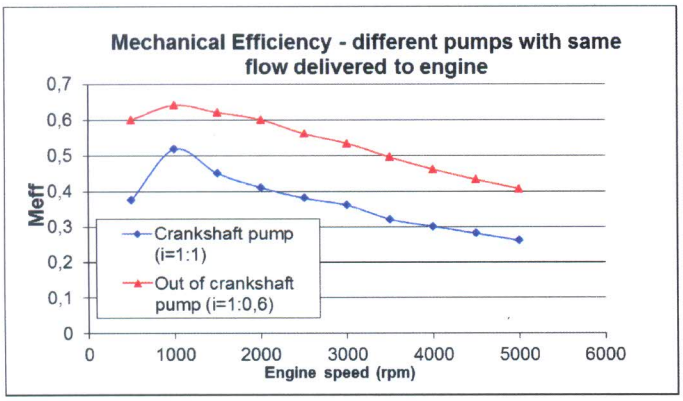


Fig.6 Mechanical efficiency of different pumps

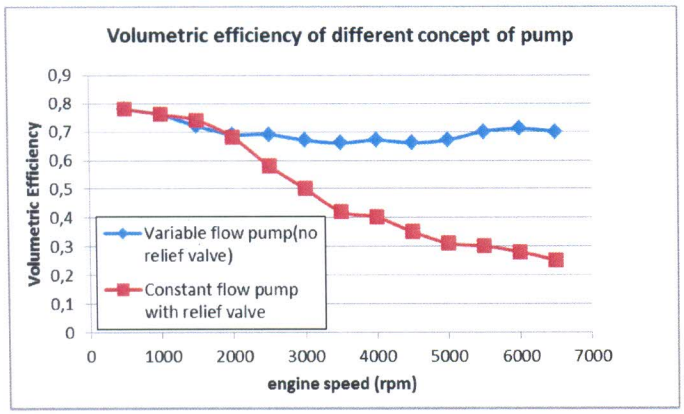


Fig.7 Volumetric efficiency of different pumps

Design of gerotor pumps can achieve flow targets with several combinations of diameter, thickness, number of teeth, etc. Special attention must be made during definition of these parameters, because efficiency is highly affected by pump characteristics.

Fig.8 shows a power draw comparison of various equivalent pumps but with different diameters [4].

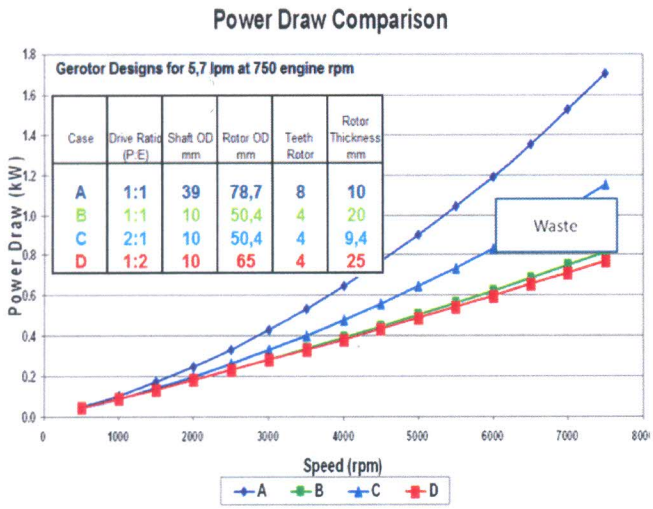


Fig.8 - Power draw comparison between equivalent delivery gerotor pumps

It can be observed that pump with smaller outside diameter is more efficient than pump with bigger diameter, due to less friction areas and leakage paths.

Based on these information, it can be verified that energy savings on oil pumps can be achieved considering the following design guidelines:

- Pump delivery that matches engine oil demand, without internal recirculation

- Smallest possible diametric package, to increase pump efficiency.

DESIGN OF ENERGY SAVING PUMPS

Variable flow oil pumps are known from long time, but application on automotive engines is recent. These pumps are more complex to produce and associated cost impact is sometimes relevant for some type of engines. There are different concepts of oil pumps, as external gear pump with axial movement; gerotor type pump with seal sector movement; vane pumps with rotating cam ; vane pumps with linear cam movement. This paper describes in more detail the vane type with rotating cam as shown on Fig.9 that is one of most common concept.

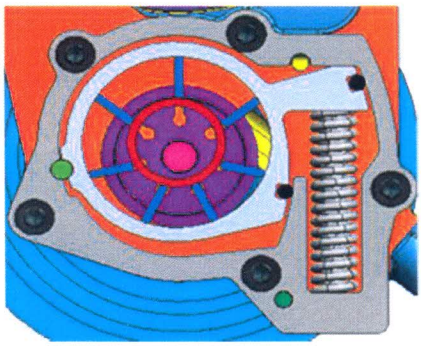


Fig.9. Typical Vane type with rotating cam

VANE TYPE OIL PUMP WITH VARIABLE FLOW

The vane type pump with variable flow is based on rotational movement of a cam in order to reduce unitary pump displacement. The cam movement must be associated with engine speed and system pressure to match with engine flow demand. This concept makes utilization of relief valve not necessary, because no excess of flow is created. Fig.10 shows basic concept of vane type with variable flow.

As discussed before, to optimize pump efficiency the ideal solution is to assemble the pumps out of crankshaft. For long

time pumps has been driven direct by crankshaft because this is the cheapest concept that can be produced, either in pump cost and Customer assembly costs. It is not possible to reduce pump diameter due to crankshaft dimension, so it is necessary some kind of transmission to drive a pump out of crankshaft.

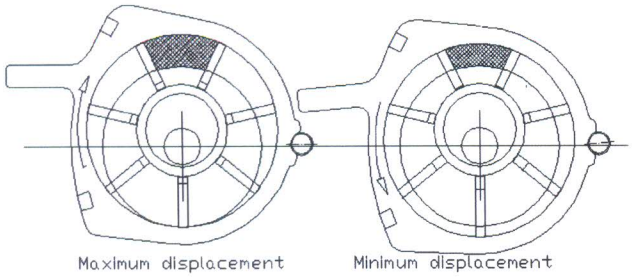


Fig.10 . Typical Vane type maximum / minimum displacement

OFF - AXIS SYSTEMS

One of the major issues of the above concept is regarding costs. The structure of pump becomes more complex and more expensive due to need of transmission systems and sometimes it becomes prohibitive. The way to reduce this drawback is to use what is called "off-axis pump", where all the transmission system is integrated in a single unity and assembly process on the engine is equivalent to traditional pumps. It saves assembly time and makes the pump simply to produce. An example of "off axis oil pump" is presented on Fig.11

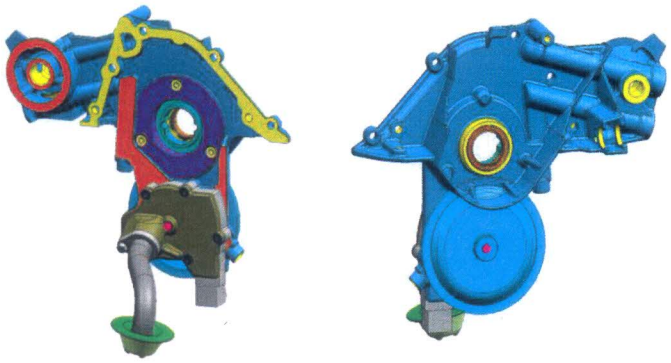
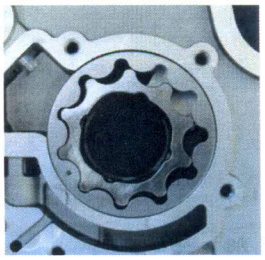


Fig.11 Example of "off-axis" oil pump

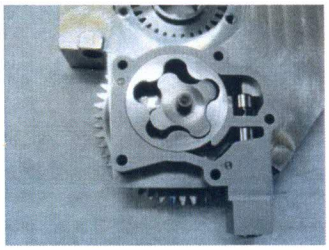
POWER COMSUMPTION COMPARISON BETWEEN PUMP SYSTEMS

To compare potential energy savings, different pumps were tested and power draw were calculated

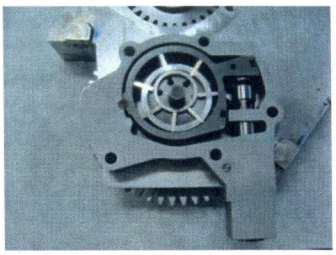
Pumps were sized to produce same flow output in order to be comparable in terms of efficiency and torque reduction. Fig.12 shows the concepts were used on the tests. Fig.13 shows equivalent oil flow demand and Fig.14 the savings in torque and power [5].



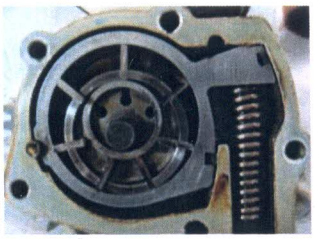
a) Constant flow- gerotor type – direct driven



b) Constant flow-gerotor type – off-axis



c) Constant flow – vane type – off-axis



d) Variable flow – vane type – off-axis

Fig. 12 – Different concept of pumps

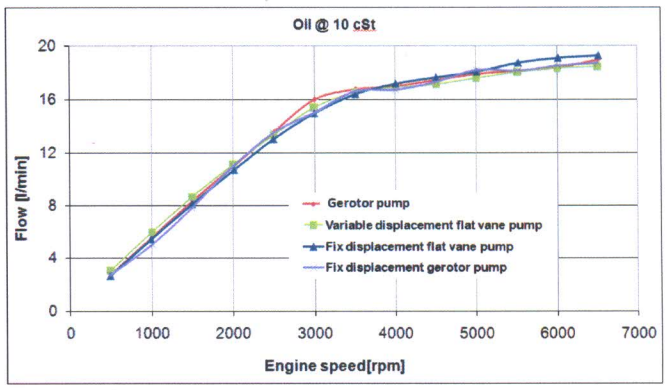
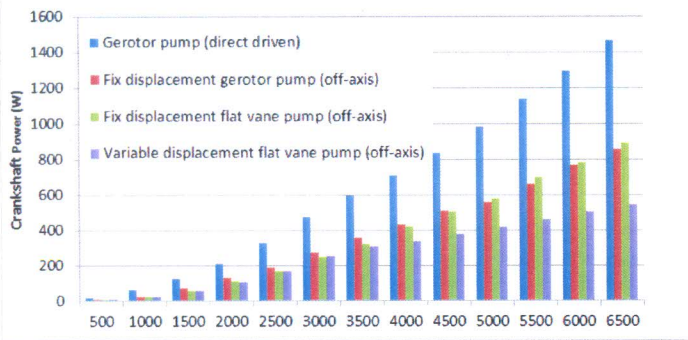


Fig.13 - Oil flow demand of pumps

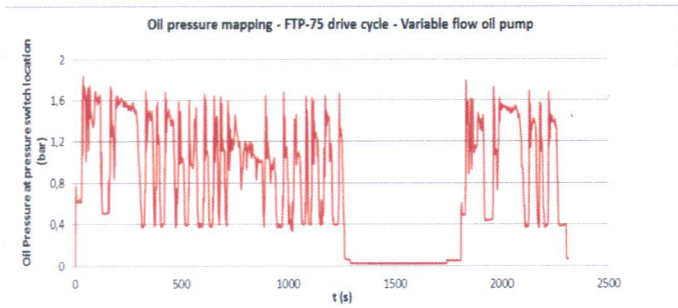


	Crankshaft power Comparison (W)						
Engine Speed (rpm)	Gerotor pump (direct driven)	Fix displacement gerotor pump (off-axis)	Saving [%]	Fix displacement flat vane pump (off-axis)	Saving [%]	Variable displacement flat vane pump (off-axis)	Saving [%]
500	19,4	7	64	6,5	66	6,2	68
1000	61	21,3	65	22,9	62	24	61
1500	124	70	44	54	56	56	55
2000	212	128	40	109	49	105	51
2500	327	189	42	168	49	170	48
3000	478	277	42	251	47	254	47
3500	600	361	40	323	46	308	49
4000	708	431	39	421	41	339	52
4500	836	509	39	503	40	378	55
5000	980	557	43	575	41	419	57
5500	1137	659	42	698	39	462	59
6000	1297	770	41	780	40	503	61
6500	1465	855	42	888	39	545	63
		Average	44,8	Average	47,3	Average	55,8

Fig.14 – Power and saving comparison

OIL PRESSURE MAPPING

As we can observe on charts above, variable flow, vane type oil pump shows best torque savings of all pumps tested. Some additional tests were performed on this pump to evaluate performance on vehicle. A FTP-75 drive cycle was used and pressures on pressure switch point were monitored to confirm that oil pressure inside engine was not affected by this pump concept. It can be observed on fig.15 that a minimum pressure of 0,4 bar is maintained even at engine idle during test cycle [6].



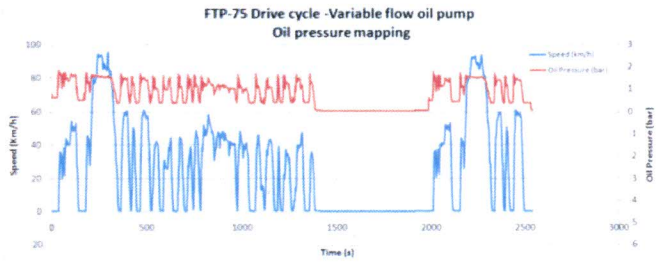


Fig.15 Oil pressure mapping

FUEL SAVINGS

In order to quantify fuel saving achievable, some engine tests were performed and fuel consumption of both situations were measured. Measurement of fuel savings is not an easy task, due to a lot of variables involved. The procedure chosen to quantify fuel savings were a constant speed test, where oil, water temperature were maintained constant and fuel flow was measured using a flow meter. An average of 30 measurement were performed and results shows potential of improvements of around 1,5 to 2,5% on engine evaluated as indicated on Fig.16 [6].

		Variable flow	Constant Flow	
Speed (Km/h)	Gear	Flow (l/h)	Flow (l/h)	Saving (%)
41,06	2	2,896	2,974	2,62
60,55	3	3,497	3,577	2,24
80,55	4	4,548	4,662	2,45
100,73	5	4,97	5,046	1,51

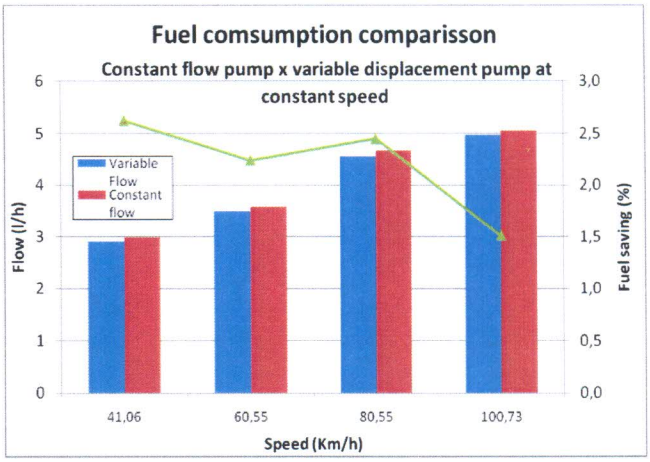


Fig. 16 Fuel consumption comparison

OIL PUMP CONTROL

Another source of energy savings is the pump electronic control. Traditional control with spring cannot permit specific strategies depending on working conditions. In order to vary flow demand according to specific situation, oil pumps can be controlled by an electro-hydraulic actuator. This device, by receiving some input from ECU, can control cam ring in order to match oil demand according to a pre-determined map based

on oil temperature, engine load, speed etc. Example of oil pump with electro hydraulic control are presented on Fig.17

Fig 17. Example of oil pump with electronic control

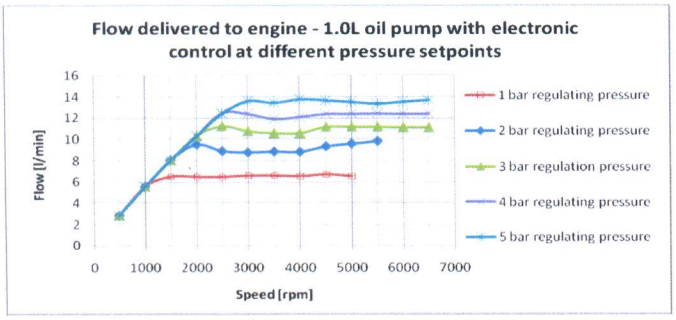


Fig 18. Possibilities to vary output flow / pressure with use of electro hydraulic pump controls.[7]

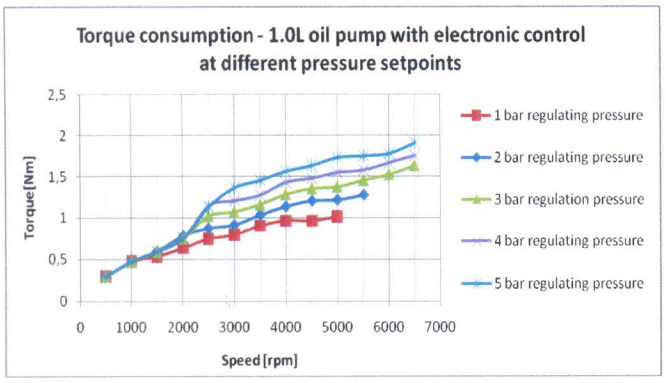


Fig.19 Torque at different pressure setpoints.[7]

SUMMARY/CONCLUSIONS

It was observed on present paper that use of variable flow pumps can be considered on development of more efficient engines, due to better efficiency that can be reached, mainly due to oil recirculation elimination, that is a important power loss source. The use of pumps out of crankshaft is also a good choice, because it permits the design of more compact pumps and application in a more favorable speed range. Oil pumps with electronic control can be considered by a proper selection of pressure set-points based on engine oil temperatures and instantaneous working conditions.

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