

## Experimental research of oil pump for a compression-ignition aircraft engine

The paper presents an analysis of the constructions of oil pumps for an aircraft compression ignition engine. It is a two-stroke liquid-cooled engine with a power of 100 kW. The system has 3 cylinders and 6 opposed pistons. The paper estimates the required oil pump capacity to make the engine components well-lubricated. Next, automotive oil pumps for diesel engines are analyzed to select a correct pump for aircraft diesel engine applications. Three pump constructions of different constructions and dimensions of a rotor were selected. A measurement bench was designed and built to test these oil pumps in the range of pump shaft speeds from 0 to 4500 rpm and volumetric flow rate up to 150 l/min. The bench also enables stabilization of oil temperature at the required level within the range from 30 to 120°C. In addition, flow resistance through engine slide bearings was simulated by changing the position of a throttling valve at the pump output to regulate pressure in the range of 0–700 kPa. The obtained capacity characteristics of individual pumps versus on oil pressure and temperature allowed us to find an appropriate oil pump to make individual engine nodes well-lubricated.

Key words: diesel engine, opposed piston engine, aircraft propulsion system, oil system, oil pump

### 1. Introduction

The oil pump is the key element of the internal combustion engine lubrication system. Its main function is to supply lubricating oil to various rotating and sliding parts of the engine to prevent engine wear and overheating. There are oil pumps with external and internal gearing called gerotor pumps. Gerotor pumps have epicycloidal wheels.

To select an oil pump for a specific engine, you should know the number of lubrication nodes, engine load and a type of oil system, i.e. open or closed. You should also bear in mind whether oil will flow through a cooler. The viscosity of oil and clearance are also important. Oil flow and pressure generated by the oil pump must be well matched to a given purpose. To drive an oil pump, you need power from an engine shaft, so the larger the flow and pressure in a pump, the more power is taken from an engine. Most engines do not require too high oil pressure at idle.

Speeds of rotary oil pumps can be limited by, e.g. cavitation. The authors of the paper [1] carried out some model tests of an oil pump for a motorcycle engine considering the cavitation phenomenon. The model was validated on a test stand. The tests were carried out for different pump speeds at an oil temperature of 100°C.

Internal and external oil leaks in the oil pump are further factors that can adversely affect oil flow and pressure. Certainly, the smaller clearance is, the higher pumping efficiency. Clearance, in turn, compensates for thermal expansion when a pump and oil heat up to high temperatures.

Increased oil temperature is more dependent on engine speed than load. Oil pressure, on the other hand, hardly affects the increase in lubricating oil temperature. It was observed, however, that it is fundamental to maintain a minimum pressure of oil that is supplied to a bearing because a rapid increase in a temperature of a slide bearing occurs when lubrication at low supply pressures is insufficient. Conversely, friction losses in a crank system do not depend on pressure in an oil system [5]. Pressure-controlled pumps are increasingly being used in lubrication systems.

The authors of work [4] developed a 3D model of an oil pump which enables the selection of appropriate geometrical parameters of the pump for automotive and aviation applications.

Both 1- and 3-dimensional simulations of pump were discussed in the works [2, 3, 7]. The authors demonstrated there, e.g. the use of 3-dimensional methods on gerotor oil pumps to verify 1-dimensional computations for larger parts of the governing oil system, to explain the test rig and engine experiments and to optimize the gerotor itself. Vane oil pumps and gerotor pumps were researched and these results are compared with the existing experimental data.

On the market, there are also available stands to measure pump capacity and its other parameters, e.g. ATA (Advanced Test & Automation) offers stands and tests of oil and water pumps for the automotive industry.

The first part of this paper presents the principles of a lubrication system of an aircraft opposed-piston compression ignition engine. Then, the requirements for the maximum volumetric flow rate are determined. Next, several pumps for compression ignition engines with the number of lubricating points similar to the designed aircraft engine are selected for the tests performed on a special test stand. The research allowed us to create maps of individual pumps and to select the pump for the designed engine.

### 2. Aircraft compression ignition engine oil pump

#### 2.1. Engine oil system

The oil pump is designed for the new construction of aircraft engines with compression-ignition and power of 100 kW. The liquid-cooled engine has 3 cylinders and 6 opposed-pistons. The engine with a capacity of 1.5 dm<sup>3</sup> is charged by means of a mechanical compressor.

A lubrication system in the planned aircraft diesel opposed piston engine (OPE) is a forced lubrication system with a dry oil sump (Fig. 1). The system is now equipped with two pressure pumps in a housing fixed to an engine block. The pumps are driven directly from engine crankshafts. The pump sucks oil from a tank by means of a heat exchanger and presses it through an oil filter to an oil main in the

engine block from where the oil is distributed to individual lubrication nodes. It is expected that the oil from the engine block will be pumped into the tank by high pressure generated by blows to a crankcase through pipes in the lower part of the oil sump. No additional oil pump is applied to dry the system. Such a solution can be found, among others, in Rotax 912/914 engines where a drying pump is the only element to suck oil from a charge compressor, whereas oil from the oil sump is pumped into an external tank by blow-generated high pressure in the engine block.

The theoretical flow rate of this pump is about 40 l/min for 4500 rpm, which gives the total flow rate of the both pumps, i.e. about 80 l/min. Regarding construction factors, the new type of engine will have a single oil pump with a flow rate similar to that of today's pumps to make the engine correctly lubricated and cooled.

According to the authors of the work, the [6] unit output of oil in the engine, depending on the  $V_{oj}$  slide bearings used, is from 18 to 35  $dm^3/(kW \cdot h)$ . This value is correct when the motor has one crankshaft, whereas in the case of a newly designed OPE motor this expenditure has to be doubled due to the use of two crankshafts.

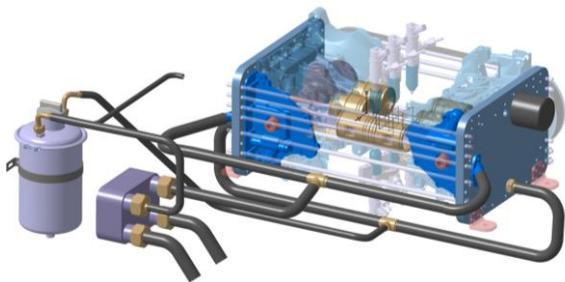


Fig. 1. External oil lubrication and cooling system OPE engine

### 2.2 Analysis of automotive oil pumps

The ideal pump for the new type of engine was selected after analyzing oil pumps with a similar number of lubrication points and a similar theoretical flow rate, typically mounted in the modern diesel engines. The aim was to select an automotive oil pump for an aircraft engine capable of achieving the required flow rate of 80–100  $dm^3/min$  at 4000 rpm. Such a flow rate is necessary because of two crankshafts, lubrication of the main gear and oil-sprayed piston surfaces to cool them. Three types of oil pumps of different rotor constructions and a similar flow rate were selected for our testing. Our research into flow rates will allow us to select the optimal pump construction for the OPE engine. Figures 2–4 show the pumps selected for the testing. The pumps have built-in oil pressure control valves.

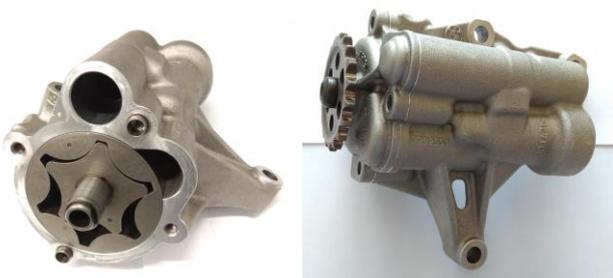


Fig. 2. Oil pump SdF, BMW M67TU D44



Fig. 3. Oil Pump Trucktec, Mercedes Sprinter 2.2 CDI

The Pierburg pump (Fig. 4), installed, for example, in the Nissan Patrol 2.8 TD, is a pump with variable flow rate.



Fig. 4. Oil pump Pierburg, Nissan Patrol 2.8 TD

### 3. Test stand

Various types of oil pumps were tested on a special test stand where flow rates of each of the pump depending on temperature and oil pressure were measured. The pump are driven by the Tamel three-phase electric engine (4 kW) with an inverter capable of engine control to guarantee an enough power reserve to drive each of the pump and to regulate pump speeds. The pumps are driven by a gearbox with a toothed belt. The gearbox consists of two HTD M8 gears with a geometric ratio of 1:1.5 or 1:2 (depending on the pump) and a 960 mm-long and 20 mm-wide toothed belt. The engine operation is stable over the entire speed range of a maximum value of 2880 rpm.

Figure 5 shows a diagram of the oil pump test stand. The Infineon KTY 19-6M/Z temperature sensor and the Wika pressure tensiometer sensor were installed in the operating chamber of each of the oil pump. The volumetric flow rate was measured with the Badger Meter IOG 1" HF equipped with an impulsor ILR740 flow meter measuring the flow rate from 5.7 to 170  $dm^3/min$  with an accuracy of 0.5%.

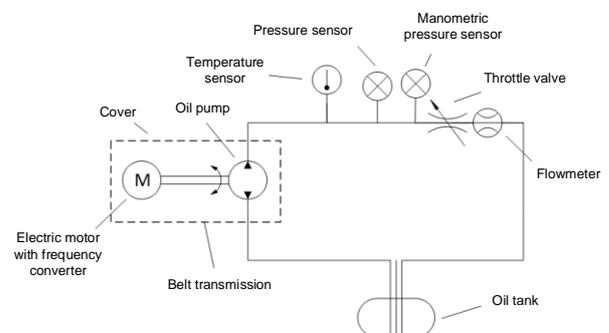


Fig. 5. Diagram of the pump test bench

The pump rotational speed was measured with a magneto-inductive sensor – Honeywell 1GT101. A 1/4 inch vol-

umetric flow control valve was mounted at the outlet from the pump chamber. Figure 6 shows the oil pump test stand.

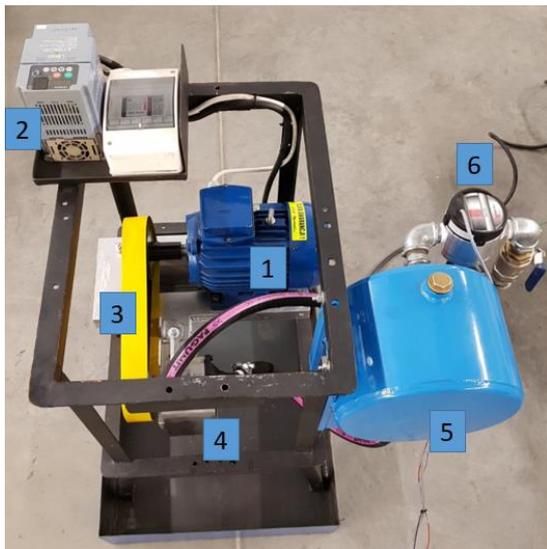


Fig. 6. Measuring station for oil pumps: 1 – electric motor, 2 – inverter, 3 – V-belt transmission with protective cover, 4 – oil pump with cover, 5 – oil tank, 6 – flowmeter

#### 4. Test conditions

The measuring points are specified by rotational speed and the degree of flow throttling given as the pressure in the system.

The tested parameters for these measuring points were: volumetric flow rate  $Q_v$  (l/min), pressure on the pumping side  $p_t$  (kPa) and oil temperature  $T_{ol}$  ( $^{\circ}\text{C}$ ). The engine speed was changed from 500 to 4500 rpm, every 500 rpm by means of an inverter. Throttling was controlled by changing the position of the ball valve, which meant a change of (absolute) pressure from 100 kPa to 700 kPa, every 100 kPa.

The tests were carried out at an ambient temperature of  $22^{\circ}\text{C}$  and an atmospheric pressure of 1010 hPa. The static pressure behind the  $p_s$  pump was equal to the sum of the atmospheric pressure and the hydrostatic pressure measured from the column of liquid above the sensor. The tests were performed for four oil temperature values:  $25^{\circ}\text{C}$ ,  $40^{\circ}\text{C}$ ,  $60^{\circ}\text{C}$  and  $80^{\circ}\text{C}$ . The oil temperature for elevated values was stabilized by means of a heating system with an electric heater and a temperature stabilization system. 5W30 oil was used for the tests.

#### 5. Test results

The conducted tests of oil pumps used in lubrication systems of diesel engines enabled us to create flow rate characteristics for each of the pumps. Figures 7–9 show the selected results of the flow rates as a function of the rotational speeds of the pump rotor in relation to the pressure at a temperature of  $80^{\circ}\text{C}$ .

The first tested pump was the SdF pump installed, e.g. in the BMW M67TU D44. It has the highest flow rate. The maximum flow rate at a speed of 4500 rpm is about 105 l/min when the pressure at the pump outlet is equal to atmospheric pressure. The pump shows a relatively linear flow rate over the entire operating range, regardless of the

oil pressure and temperature. For an oil temperature of  $80^{\circ}\text{C}$  and a pressure of 700 kPa, the maximum flow rate is 92 l/min, which is less by approx. 13 l/min.

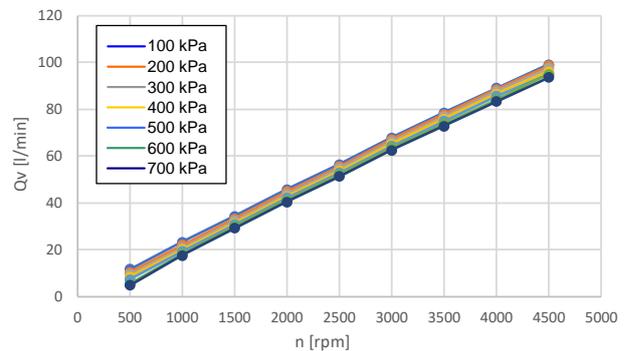


Fig. 7. Volume output as a function of speed for defined pressure values for SdF oil pump

Figure 7 shows the volumetric flow rate for the Pierburg pump as a function of speed. The measurements were without flow throttling for speeds ranging from 500 rpm to 4500 rpm. The obtained correlation of the flow rate and the pump speed is linear nearly in the entire speed range. The volumetric flow rate of the pump varies from 10 to 89 l/min.

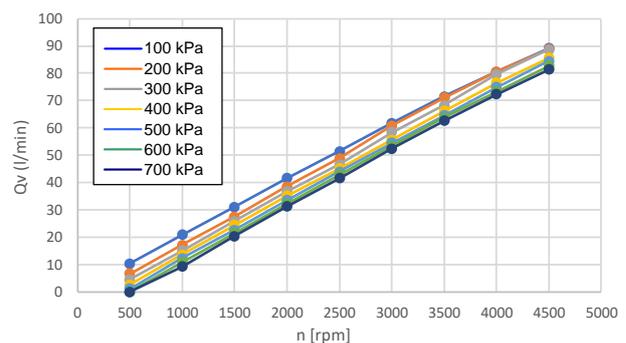


Fig. 8. Volume output as a function of speed for defined pressure values for Pierburg oil pump

The flow rate for the Trucktec pump (Fig. 8) for the pressure range of 100–500 kPa is linear over the entire speed range of the pump rotor. The maximum flow rate is 78 l/min at a speed of 4500 rpm. When the oil pressure was increased depending on the speed, the pump flow rate changed a lot.

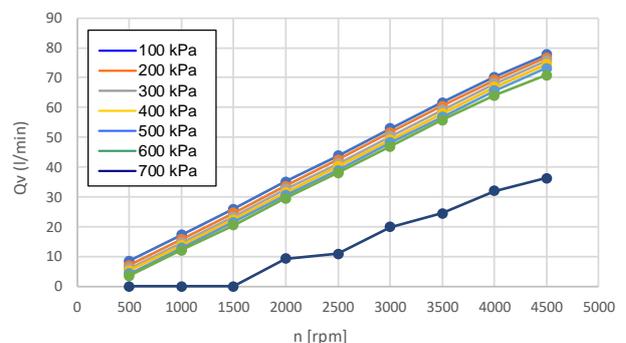


Fig. 9. Volume output as a function of speed for defined pressure values for Trucktec oil pump

The pump generates a much lower flow rate at a pressure of 700 kPa, which is related with opening the bypass valve above 600 kPa.

Figures 10–12 show the dependence of the pump output on the rotational speed for different oil temperatures. In each case, an increase in the oil temperature caused a decrease in the oil pump output.

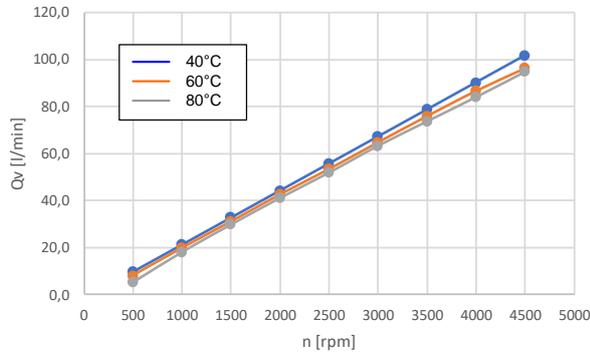


Fig. 10. Volume output as a function of speed at 600 kPa and a defined temperature value for the BMW SdF oil pump

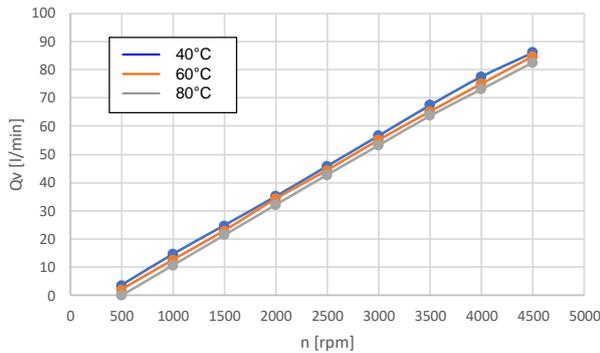


Fig. 11. Volume output as a function of speed at 600 kPa and a defined temperature value for the Pierburg oil pump

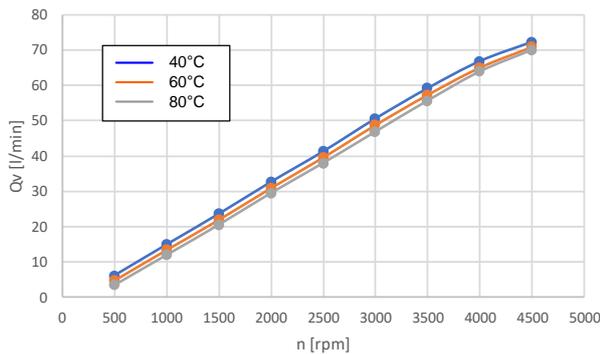


Fig. 12. Volume output as a function of speed at 600 kPa and a defined temperature value for the Trucktec oil pump

The highest decrease was observed for the SdF BMW pump, about 7 l/min, for other pumps this decrease did not exceed 3.5 l/min.

Figure 13 presents a comparison of the flow of three tested pumps for oil pressure of 600 kPa and temperature of 80 °C. The SdF BMW SdF pump had the highest flow rate of 94 l/min, while the Trucktec pump had the lowest flow rate. The difference was about 24 l/min.

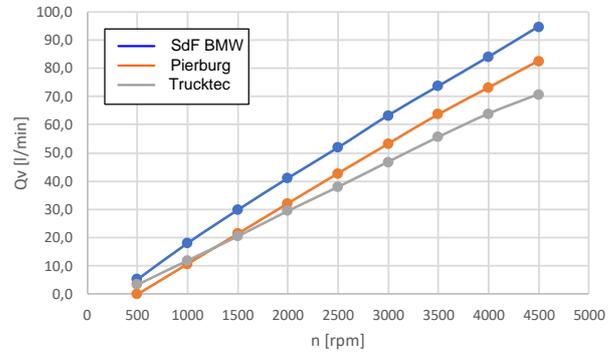


Fig. 13. Oil pump volume flow for 600 kPa pressure and 80 °C oil temperature

## 6. Summary

The tests of the flow rates of the automotive oil pumps were to gain certain necessary data, i.e. changes in pressure, flow rate and the impact of oil temperature on flow rate and develop an assembly of pumps efficiently lubricating the OPE engine. The obtained results enabled us to create the characteristics of the pump operations. It was noticed that the flow resistance has a significant impact on pump's operating parameters, i.e. flow and pressure. The increased oil temperature decreased the pump flow rates in each case. The maximal drop was 9% for the Trucktec pump. The obtained necessary data includes: data on the construction and operation of oil pumps, the maximum flow rates of each of the pump, operating pressure ranges, the correlation between pump flow rates and pressures and temperatures for a given pump speed, and operating ranges for oil pressure control valves.

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## Nomenclature

OP Oil pump  
 OPE Diesel Opposite Piston Engine  
 RPM Revolutions per minute  
 ICE Internal combustion engine

CI compression ignition  
 VFR Volumetric flow rate

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