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Article

Design and Development of a Dual-Cavity Oil Pan for an Engine

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Abstract: This paper studied the design and development of a dual-cavity oil pan for an internal combustion engine. By analyzing the working principle of the dual chamber oil pan and considering the target requirements, relevant parameters are determined to meet the requirements of rapid oil temperature increase, friction reduction, and fuel consumption reduction.

Keywords: dual chamber oil pan; oil temperature; high strength

1. Introduction

In recent years, with the release of the four stage fuel consumption regulations for commercial vehicles, various engine manufacturers have taken various measures to save energy, reduce emissions, improve fuel efficiency, and lower operating costs in order to meet national standards. One of the important measures is to reduce friction, decrease the friction of some key components, and improve lubrication. In this case, the development of a dual chamber oil pan [1] can optimize the lubrication system. The main principle is to heat the oil in the oil pan in batches, first heating and reaching the appropriate temperature of some of the oil, and lubricating the engine with residual circulation in advance, thereby achieving rapid heat up effect. The rear heating part will gradually participate after the subsequent heating is completed, which greatly saves the engine warm-up time, ensures the normal operation of the engine, improves fuel efficiency, and reduces fuel consumption.

The oil pan is a container for collecting and storing engine oil, which together with the cylinder block forms the engine crankcase and also plays a role in dissipating oil heat. The shape and size of the oil pan depend on the overall layout of the engine, the required oil capacity, and the vehicle's requirements for the external dimensions of the engine. The oil capacity of the oil pan should meet the requirements of the engine's range and the vehicle's oil should not be sucked out under various working conditions.

This article designs a dual chamber oil pan for a certain type of engine. Under various boundary conditions provided by the entire vehicle, the basic shape of the oil pan is determined based on the required engine oil capacity. After calculating the engine oil flow rate, the internal oil capacity of the dual gun oil pan is confirmed, and the detailed plan for the internal and external oil inlets and drain bolts is finally determined. Considering the requirements of lightweight and vehicle reliability [2], the inner cavity of the dual chamber oil pan adopts plastic parts, and the outer cavity adopts cast aluminum parts. These specific measures have guiding significance for the design and development process of the dual chamber oil pan [3,4].

2. Oil Capacity Calculation

Due to the fact that the engine matched with the oil pan is a newly developed design, there is no reference model for the oil pan design, and the oil pan needs to be conceptually designed first [5,6].

The oil capacity first determines the volume of the oil pan, which is designed according to the requirements of the vehicle's range. According to the reliability test data of the engine, the oil fuel consumption ratio (required by China VI to be 0.1%) and the average fuel consumption are 16.7g/h. From the engine fuel ratio data, it can be concluded that the approximate oil consumption per 10,000 km is 1.67 kg. However, using the oil density (taking Castrol as an example) of 0.855 kg/L, the maximum oil consumption per 10,000 km can be converted to 1.955 L. The maximum scale line of the oil pan designed in this article is 11 L (20,000 km without oil), so the minimum capacity of the lower scale line of the oil dipstick is 7.09 L (11–3.91), which means that the maximum and minimum oil capacities of the oil pan on the upper and lower scale lines of the oil dipstick are 11 L and 7.09 L, respectively. The above is the analysis data of the engine under the worst conditions.

3. Oil Flow Calculation

3.1. Principles of Computing

According to experience, the number of oil cycles in the diesel engine oil pan is 8–10 times per minute. Calculate the internal capacity of the dual chamber oil pan based on the number of oil cycles in the oil pan and the engine oil flow rate.

3.2. Calculation Formula and Results

The parameters in the following formula are all national standard parameters.

$$L_1 = L_2/C(L)$$

L_1: The amount of oil in the inner cavity of the oil pan, unit: L;
L_2: Rated engine speed and oil flow rate, unit: L/min;
C: Number of oil cycles, unit: times/min;

$$L_2 = \Phi_j/(r * c_j * \Delta t)$$

Φ_j: Oil heat dissipation, unit: kJ/h; 27,600;
r: Oil density, unit: Kg/L; value: 0.855;
c_j = Specific heat capacity of engine oil, unit: kJ/kg ℃; value: 2.1;
Δt = The engine oil completes one cycle and heats up, unit: Δt; value: 15°;
After calculation L_1 is 2.13 L, Considering the safety factor, t will be multiplied by n (taken as 1.2), and the final L_1 is 2.56 L.

4. Three-Dimensional Design of Oil Pan

4.1. Boundary Confirmation

The requirements for engine compartment space [7,8] and ground clearance of the entire vehicle constrain the basic shape of the oil pan. For general models, the gap between the bottom of the oil pan and the ground is greater than 150 mm. The boundary of the oil pan in this development is shown in Table 1.

Table 1. Oil pan boundary requirements.

Category	Standard	Part
engine installation	≥15 mm	compared to the frame left front suspension of engine right front engine suspension
static	≥200 mm	ground clearance
dynamic	≥150 mm	ground clearance
	≥30 mm	compared to the front leaf spring horizontal with the front leaf spring compared to the upper limit of the front axle

4.2. Material Selection

Nowadays, engines require lightweighting, so many oil pan materials are made of plastic, which has a density only half of commonly used aluminum and reduces overall weight. However, the oil pan developed in this article is connected to the flywheel housing at one end and needs to be fixed with bolts, which requires high strength [9–14]. At the same time, although the plastic oil pan has the advantage of lightweight material and can also reduce noise, the common aluminum alloy material ADC12 is still used for the outer cavity of the oil pan in this development, and the plastic material is used for the inner cavity. The materials for the oil pan in this development are shown in Table 2.

Table 2. Material Properties of Oil Bottom Shell.

Part	Oil Pan on the Outer Chamber	Oil Pan under the Outer Chamber	Internal Cavity Oil Pan
material	ADC12	SP122	PA66 + GF30
densitykg/m^3	7000	7850	1300
elastic modulus Mpa	27,000	21,000	/
poisson's ratio	0.33	0.3	/

4.3. Model Structure Layout

The use of a dual chamber oil pan is to quickly increase the temperature of the engine oil. Therefore, the oil contact area of the inner chamber oil pan should be as large as possible to ensure that the engine oil is received after circulating in the oil passage of the engine block, allowing the temperature of the inner chamber oil pan to quickly increase with "less oil", improve the lubrication system, and reduce mechanical friction. After theoretical analysis, the gap between the upper end of the inner cavity of the dual chamber oil pan and the outer cavity oil pan for oil connection was determined to be 1.6mm. The relevant oil connection data are shown in Table 3.

Table 3. Oil Connection Data.

Top Area of Inner and Outer Cavities	Area (mm^2)
Total area	115,536
inner cavity	105,256
external cavity	10,280
Acceptance rate	91.1%

The internal layout of the dual chamber oil pan not only needs to consider the oil collector, but also the hydraulic valve, temperature control valve, internal oil discharge valve and other components. Reasonable positioning will greatly improve the oil suction and discharge efficiency. The oil collector in this article is located near the middle of the rear end, with the inner oil pan as low as possible to ensure that more oil is sucked in. The specific structure is shown in Figure 1, and the internal features are shown in Figure 2.

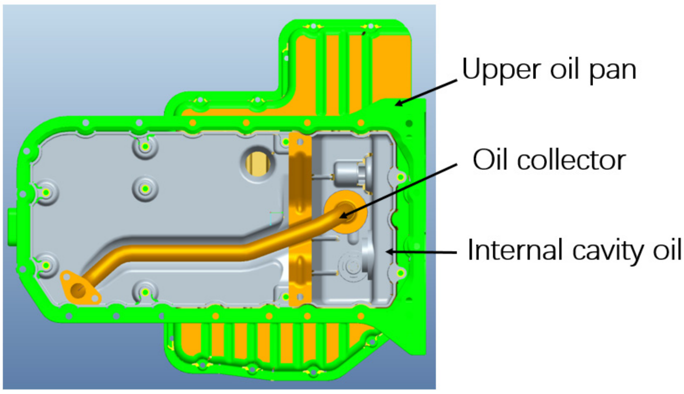

Figure 1. Overall structure of oil pan.

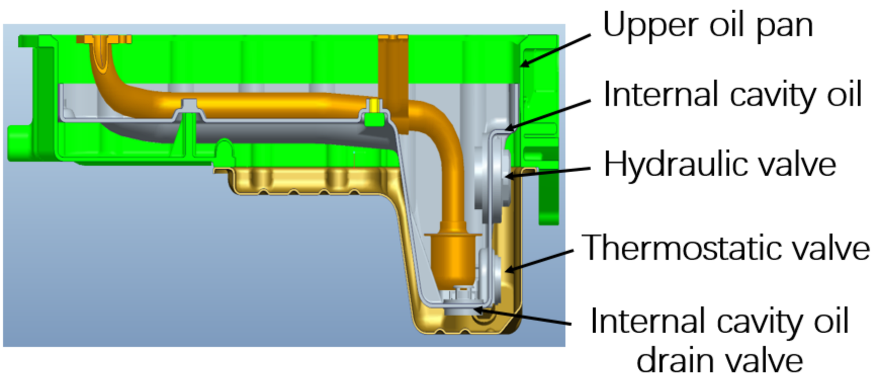

Figure 2. Internal structure of oil pan.

4.4. Determination of Internal Cavity Oil Replenishment Position

When the whole vehicle is running, it is necessary to consider the relationship between the oil collector port and the oil position when the engine tilts left and right by 38.7° and goes up and down by 18°, to ensure that there is no suction. Therefore, it is necessary to verify the safe oil level in the internal cavity. The specific verification data is shown in Table 4.

Table 4. Safe Oil Volume in Inner Chamber.

Vehicle Driving Status	Safe Fuel Quantity (L)
Turn left	0.9
Turn right	1
Upslope	0.7
downhill	0.6

According to the volume of the inner cavity minus the safe oil volume, the position of the inner cavity oil replenishment and the position of the inlet valve can be determined, as shown in Figure 3.

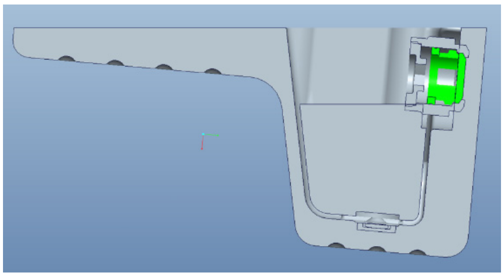

Figure 3. Oil replenishment position.

4.5. Determination of External Chamber Oil Volume

To ensure that the connecting rod does not stir up oil, the outer chamber oil volume can be calculated based on the target value of the oil pan design and the internal chamber oil volume. The specific calculation results are shown in Table 5 and Figure 4.

Table 5. Internal and External Chamber Oil Volume.

Position	Fuel Level (L)
Total capacity	10.5
inner cavity	2.6
external cavity	7.9

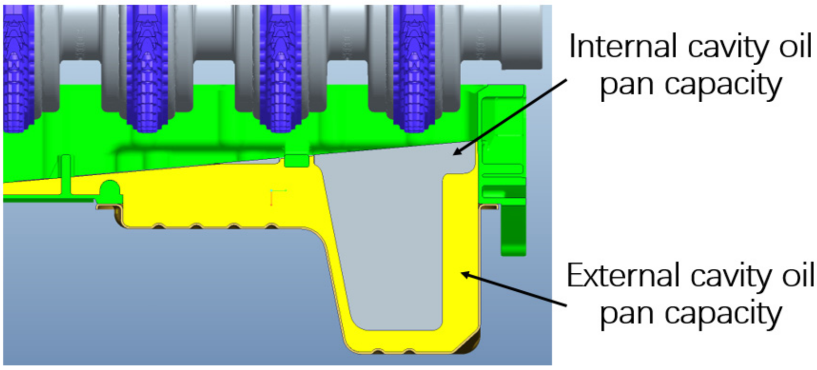

Figure 4. Oil volume in inner and outer chambers.

4.6. Hydraulic Valve Determination

The function of the hydraulic valve is to replenish the inner oil pan through pressure difference when the oil level in the inner oil pan is too low and the oil level in the outer oil pan is higher than the oil level in the inner oil pan, ensuring that there is enough oil in the inner oil pan. Please refer to the Figure 5 for details.

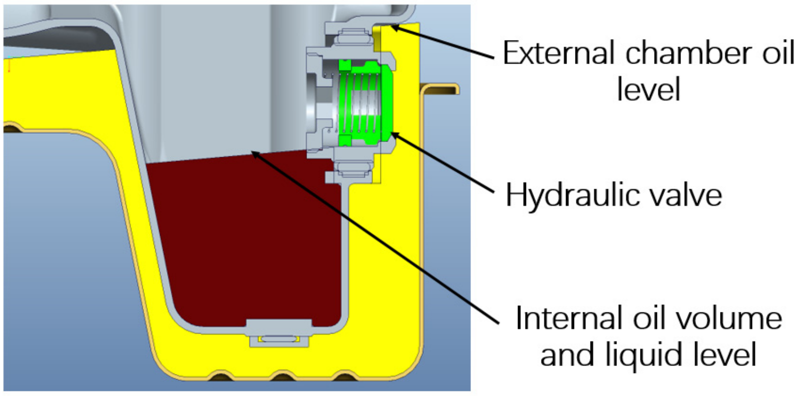

Figure 5. Working principle of hydraulic valve.

The hydraulic valve is an important key component, and the related parameter settings affect the oil replenishment opening conditions and oil replenishment flow rate, ultimately affecting the engine lubrication system. The development of this article focuses on some specific parameters, as shown in Table 6.

Table 6. Relevant parameters of hydraulic valves.

Difference in liquid level height between inner and outer chambers (mm)	47
Oil density (kg/m^3)	8.55×10^2
Internal and external pressure difference cross-sectional area diameter (mm)	26
Spring stiffness (kg/mm)	13.6
Effective number of coils of spring	12.5
Spring center diameter (mm)	22
Spring height (mm)	18.75
Inlet flow rate (m/s)	0.96
Flow rate per second (L/s)	0.139
Inner cavity filling time (s)	16.5

5. Product Acceptance Evaluation

The oil pan is an important core component of the engine, with technical requirements for finished material, surface quality, size, sealing, and defects, as shown in Table 7.

Table 7. Acceptance Confirmation Items.

Number	Confirmation Project	Remarks
1	chemical composition	Meet the requirements of the drawings
2	Mechanical properties (test bar)	Consensus on supply and demand
3	Geometric dimensions	Meet the requirements of the drawings
4	Casting quality and defects	Consensus on supply and demand
5	cleanliness	Meet the requirements of the drawings
6	sealing performance	Consensus on supply and demand
7	rust prevention	Meet the requirements of the drawings

The oil pan developed this time meets the delivery standards and can be equipped with relevant tests to carry out related work on reducing engine fuel consumption.

6. Conclusions

In recent years, China's automotive industry has developed rapidly, and there are more and more engine fuel saving technologies. The dual chamber oil pan technology is now very mature and becoming increasingly popular in the market, but various problems still arise. The root cause is that the current design standards are not specific enough, and the relevant details are not detailed enough. Therefore, standardizing the relevant parameters and clarifying the relevant details is a top priority for designers. This article has certain reference and guidance significance for other design engineers in the development of dual chamber oil sump. It can not only reduce risks in advance, but also reduce development cycles and costs. It is also a good cost reduction measure for enterprise development.

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