GENERAL CALCULATION OF I.C. ENGINE LUBRICATION SYSTEM
TÍNH TOÁN TỔNG THỂ HỆ THỐNG BÔI TRƠN ĐỘNG CƠ ĐỐT TRONG

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ABSTRACT

This paper presents a new calculation method for internal combustion engine (I.C. Engine) lubrication system. The main objective of this method is to establish pressure - volumetric flow curves of the lubrication network and of the oil pump according to designing and working parameters of the engine. Then the working point of the system will be determined through the intersection of these two curves. Based on the found working point, the pressures and volumetric flows of all units are specified. With these values, a traditional calculation for these units can be implemented reliably to conclude if these units are suitable for the system and how the working situation of the whole system is. To solve this matter lightly, a general calculating program on Matlab-Simulink was built. The diesel D243 engine was chosen as an object for the calculating program. The method developed was proved to be able to calculate I.C. Engine lubrication system either for new engine design or for test calculation of in-used engines. Moreover, it can be used to calculate pressurized lubrication systems of other mechanical machines.

Key words: Lubrication system calculation, Matlab-Simulink.

TÓM TẮT

Bài báo trình bày một phương pháp tính toán mới bổ sung cho tính toán truyền thống hệ thống bôi trơn động cơ đốt trong. Nội dung chính của phương pháp là thiết lập đặc tính lưu lượng - áp suất của lưới và của bơm dầu theo đúng sơ đồ bố trí, kết cấu các phần tử của hệ thống cùng với các thông số làm việc cụ thể của động cơ. Từ đó, điểm làm việc của hệ thống được xác định chính là điểm cắt nhau của hai đặc tính. Trên cơ sở điểm làm việc sẽ xác định được áp suất và lưu lượng của mọi phần tử trong hệ thống. Các giá trị này sẽ được dùng trong tính toán truyền thống cho từng phần tử để khẳng định rằng, phần tử đó có phù hợp cho hệ thống hay không và tình trạng hoạt động của toàn bộ hệ thống ra sao. Toàn bộ quá trình tính toán được thể hiện trong một chương trình xây dựng trên Matlab-Simulink và động cơ diesel D243 được chọn làm đối tượng cho một ví dụ áp dụng phương pháp. Từ sự hợp lý của các kết quả tính toán thu được và từ cách thức xây dựng phương pháp có thể kết luận rằng, phương pháp tính toán tổng thể có thể dùng không những để tính toán thiết kế mà còn để tính toán kiểm nghiệm hệ thống bôi trơn động cơ đốt trong. Ngoài ra, phương pháp này cũng có thể mở rộng để tính toán hệ thống bôi trơn cưỡng bức của máy móc cơ khí nói chung.

I. INTRODUCTION

Lubrication system is one of most important systems of internal combustion engines (I.C. Engines). It affects greatly mechanical losses, wear and lifetime of the engine. Appropriate choose of units of this system is one of main contents of the I.C. Engine calculation and design. However, the calculation and design in I.C. Engine textbooks up to now [1-3] have been described separately, which causes many difficulties to choose proper units for the system during new engine design or test calculation for in-used engines. To overcome this difficulty it is necessary to set up a simulation program to calculate generally the whole lubrication system, in which all system units are simultaneously investigated according to their real lay-out on the engine.

II. MODEL AND SIMULATION

2.1 Model of the lubrication system

Many types of lubrication for I.C. Engines are currently available, such as oil splash by moving engine parts in the crankcase, oil blended in gasoline in some small two-stroke-gasoline engines or pressurized lubrication by a pump [1-3]. The most popular among these types is the last one which is classified in two types, wet-sump and dried-sump lubrication system with many different constructions and lay-outs. Fig. 1 is one of wet-sump lubrication systems.

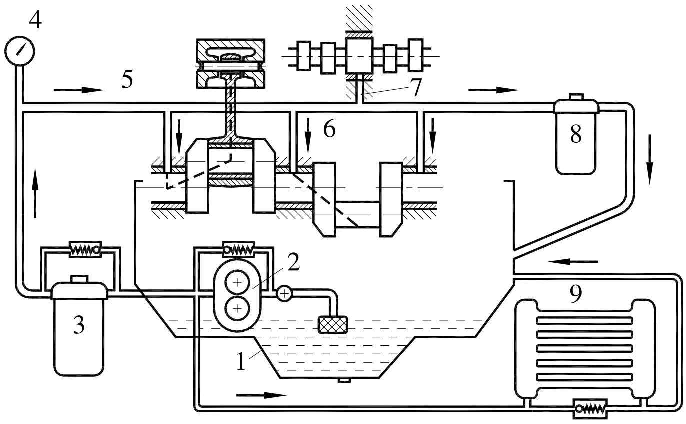

Fig.1 A wet-sump lubrication system lay-out

1: sump, 2: oil pump, 3: rough oil filter, 4: oil pressure gauge, 5: main oil gallery, 6: crankshaft lubricating line, 7: camshaft lubricating line, 8: fine oil filter, 9: oil cooler

To simplify the model the following assumptions were used:

- The working state of the engine is stable and the calculation is carried out at the norm engine out-put.

- Viscosity of lubricating oil depends only on the temperature.

- In- and out - unit temperatures are chosen according to [1], but the temperature in the journal bearings is determined for the control purpose basing on the balance between the thermal energy released by friction and the calorie taken away from the bearing by the oil [1].

Units of the lubrication network (not including oil pump), which have flow resistance, cause pressure loss. These units can be classified into 2 groups. The first one consists of the so called oil consumption units having such a characteristic that oil after passing the units drains to the oil sump. This group includes journal bearings lubricated by pressurized oil, oil cooling branched-off radiator 9, fine filter 8 (Fig. 1) and oil nozzles (for instance nozzle to cool down the piston top or nozzle of centrifugal filter). Belong to the second group are non-consumption units, such as rough filter 3 (Fig. 1), in series oil cooler, connecting parts and pipes. Each unit of the lubrication system (also including oil pump) has the volumetric flow-pressure characteristic dpecified by $V = f(\Delta p)$ equation (where Δp: pressure difference of oil passing the unit). This characteristic is determined according to the methods described as follows.

The characteristic of journal-bearings (shortly called hereinafter bearings) is given by the following equation [1]:

$$V = \zeta d^2 \omega \Delta + \frac{A\alpha(p - p_0)d\Delta^2}{l\mu} \ (cm^3/s) \quad (1\text{-}1)$$

ξ and α: coefficients depending on relative eccentricity of the bearing $\chi = \frac{e}{\delta}$ (e: absolute eccentricity; δ: bearing interstice value) and on $\frac{l}{d}$ (l and d: bearing length and diameter) [1];

ω: angle velocity $\omega = \frac{\pi n}{30}$; n: engine revolution (rpm);

Δ: bearing radial interstice $\Delta = 2\delta$;

A: loaded area coefficient chosen according to [1];

μ: oil viscosity (depending on temperature);

p: pressure at bearing inlet; p_0: atmospheric pressure.

The characteristic of oil nozzles can be determined as follows:

$$V = \mu f \sqrt{\frac{2(p - p_0)}{\rho}} \quad (1\text{-}2)$$

μ: nozzle flow empirical coefficient according to [7]; f: nozzle orifice area;

p: nozzle inlet pressure;

ρ: oil density.

The characteristic of fine filter 8 and oil cooler 9 (Fig. 1) $V = f(p - p_0)$, in principle, can be calculated following (1-2) [1] or experimented if it is not delivered by the manufacturer.

For the rough filter 3 (Fig. 1), it is acceptable that the oil flow depends only on the difference of the inlet and outlet pressure of the filter ($\Delta p = p_{in} - p_{out}$), but not on each individual pressure. Similarly, its characteristic $V = f(\Delta p)$ can be either calculated [1] or experimented.

By the connecting parts, pipes and lines, the location and route pressure losses are correspondent mainly to their structure and oil velocity, their characteristic is determined in detail in [7].

From the above-determined pressure loss characteristics, an equivalent resistance curve of the network referred to the pump outlet can be obtained and called as the net curve V_n (Fig. 2). It is necessary that the volumetric flow at the referred point has to be equal to the sum of flows of all oil consumption units in the network.

for the oil pump, its volumetric flow-pressure curve (also called pump characteristic V_p) (Fig. 2) can be either semi-empirically calculated or built only by an experiment.

The working point of the system (V_w; p_w) at the considered regime is the intersection of the net and pump curves (Fig. 2).

From the found working point and basing on the net curve, the flow and pressure at any point in the oil network can be determined.

With the determined inlet bearing pressure, the oil temperature in each bearing is calculated to assure if the safe condition (below 110^{0}C) and the wet-friction lubricating condition are satisfied [1].

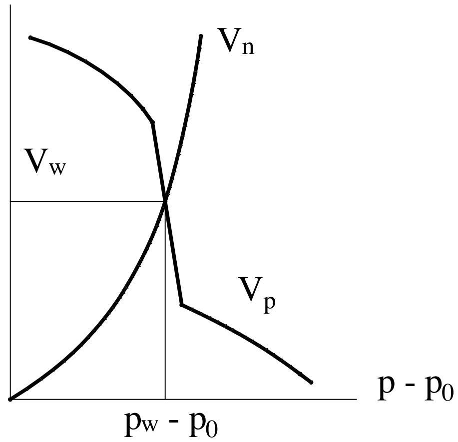

Fig.2 Determination of system working point

2.2 Calculating method

To solve the considered problem, a program on Matlab-Simulink was built, which includes following blocks:

- Subprograms for V-p characteristics of:

• Oil consumption units, such as main bearings, com-rod bearings, camshaft bearings and oil injecting nozzles;

• Oil non-consumption units, for instance rough and fine filters (including penetration and centrifugal filters) and oil cooler;

• Oil pump.

Fig. 3 describes one of such subprogram for main bearing as an example.

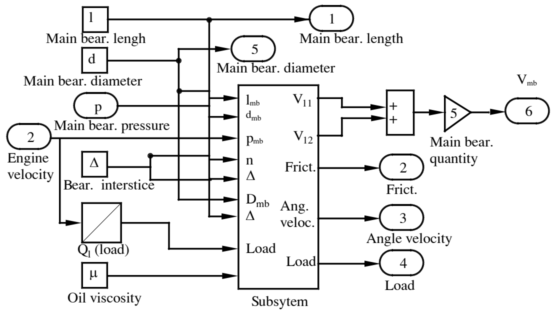

Fig.3 Subprogram for main bearing

In subprograms for main bearings and con-rod bearings, some experimental graphs [1] are interpolated by Lagrange [4] and the temperature of inlet bearings is chosen experientially among 70 - 75^{0}C [1] to determine oil viscosity [5].

- Main program for the network curve creation and for finding the working point of the whole lubrication system.

- Other subprograms to control the oil temperature and hydraulic lubricating condition in the bearings according to [1].

III. APLICATION FOR DIESEL D243

To apply the developed calculating method, the diesel engine D243 was chosen as an objective. Main specifications of this engine are shown in Tab 1.

D243 is a four-stroke four-cylinder in-line water-cooled natural-aspirated diesel engine, which was manufactured and assembled in Disoco company in Vietnam under the design in Belarus basing on the diesel engines D50 series, in order to be used on tractors and small ships.

Other necessary economical and technical specifications of D243 are listed in detail in [5].

Table 1. Main specifications of diesel engine D243

Ord.	*Item/Symbol*	*Value*	*Unit*	*Ord.*	*Item/Symbol*	*Value*	*Unit*
1	Bore (D)	110	mm	4	Rated power output /revolution	80/2200	hp/rpm
2	Stroke (S)	125	mm	5	Firing order	1-3-4-2	-
3	Compression ratio (ε)	16,4	-	6	Fuel consumption	183	g/hp.h

3.1 D243 lubrication system

The lubrication system of D243 belongs to wet-sump type and is shown in Fig. 4. It uses only one fully centrifugal oil-filter 4, in which oil is partly injected through two nozzles causing torque that rotates its rotor and then drains to the sump 1 while filtered oil flows into the main oil gallery 6. From there oil is leaded to five main bearings of the crankshaft 8 through the branched drains 7 in the engine block and then flows in four drilled drains of the crankshaft to the con-rod bearings. Thecamshaft 10 has three bearings lubricated by oilfrom the main oil gallery 6 through the branched drains 9. The specifications of all the bearings and of the lubrication system that are necessary for the calculation are given thoroughly in [5].

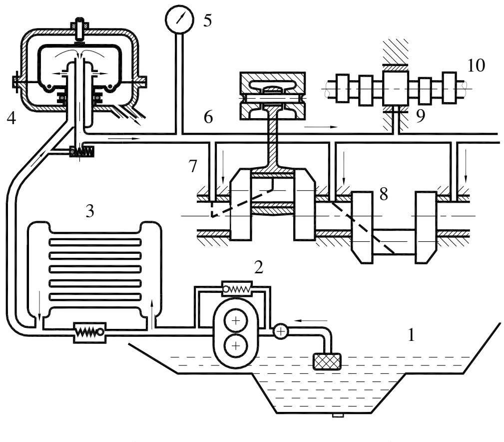

Fig. 4 Lay-out of the lubrication system of diesel D243

1: sump, 2: oil pump, 3: oil cooler, 4: fully centrifugal oil filter, 5: oil pressure gauge, 6: main oil gallery, 7: crankshaft lubricating line, 8: crankshaft, 9: camshaft lubricating line, 10: camshaft

3.2 Calculating program and results

The subprograms to build characteristic of main bearings, con-rod bearings, camshaft bearings, and of other units such as centrifugal oil filter 4 and oil cooler 3 (Fig. 4) and the main program for the net curve are shown in detail in [5].

Particularly, for the oil pump of D243, since its characteristic given by the manufacturer is not available, the authors already tested the pump on the pump test bed MIRKOR (Hungary) at ICE Lab, Hanoi University of Technology, at 1320 rpm (relevant to 2200 rpm in the diesel engine D243), Fig. 5, to establish the pump curve. The oil used in the test is HD50 having dynamic viscosity of 16,3 – 21,9 cSt at 100^0C. The oil temperature is maintained at 85^0C by an electric heater and the pump output pressure is variable through a throttle valve from 4 to 10 at [5]. The test results shown in the Tab. 2 are inputed into the subprogram to get the pump function $V_p = f(p_p - p_0)$ through Lagrange interpolation method [4].

Table 2. Test results of the oil pump of diesel D243

V_p (cm^3/s)	492,5	425,3	394,4	375,6	356.7	309,9	277,5
p_p (at)	4	5	6	7	8	9	10

Basing on all aboved-mentioned programs, a general program to calculate lubrication system of diesel engine D243 was built and shown in the Fig. 6. After runing this program, the results were obtained as follows: pump volumetric flow 373,50 cm^3/s, pressure in the main oil gallery 7,1 at (Tab. 3). These results are fully agreed with data of tractor and automobile diesel engines [1-3].

The program of calculation of thermodynamics, kinetics and dynamics of four-stroke engines [6] built by ICE department of HUT was used to calculate loaded graphs of main bearings and con-rod bearings at the rated engine power.

Using the found values of bearing inlet pressure in Tab. 3, the hydraulic lubricating condition and the temperature in the bearings were calculated according to [1]. The control results, for instance the temperature in main bearings was 93^0C, Tab 3, finally proved that all the requirements were met for the engine D243 [5].

At last, the centrifugal oil filter and the oil cooler were also calculated according to [1] at pressures and flows found from the general calculation. The control calculation for these units also demonstrated that they are suitable for the diesel engine D243 [5].

Fig. 5. Test apparatus for the oil pump of diesel D243

IV. CONCLUSIONS

The aboved - mentioned calculation considered generally all units of lubrication system under the concrete working conditions of the engine, so it is closer to the reality and at the same time the calculating procedure is clearer. Finding of the working points of the network is important for oil prerssure and oil flow to be obtained in order to control the hydraulic lubricating condition for the bearings, oil temperature in the bearings, capacity and quality of oil filters more visually.

The calculation also proved that changing working parameters of any unit in the system will affect the whole system working.

The calculating method developed within this research can be used either to design or to assess I.C. Engine lubrication system. Besides, it can be also suitable for choosing reasonable system units.

Finally the calculating method is believed to be able to to calculate pressurized lubrication system not only for I.C. Engine in particular but also for other mechahnical machines in general.

Table 3. Generally calculating results for the lubrication system of diesel engine D243

Centrifugal oil filter		*Main bearing*		*con-rod bearing*		*Camshaft bearing*		*Oil pump*		*Oil temperature in main bearing (^0C)*
p(at)	V(cm^3/s)	p(at)	V(cm^3/s)	p(at)	V(cm^3/s)	p(at)	V(cm^3/s)	p(at)	V(cm^3/s)	
6,30	349,94	6,30	12,65	6,10	10,28	6,10	0,63	7,10	373,50	93

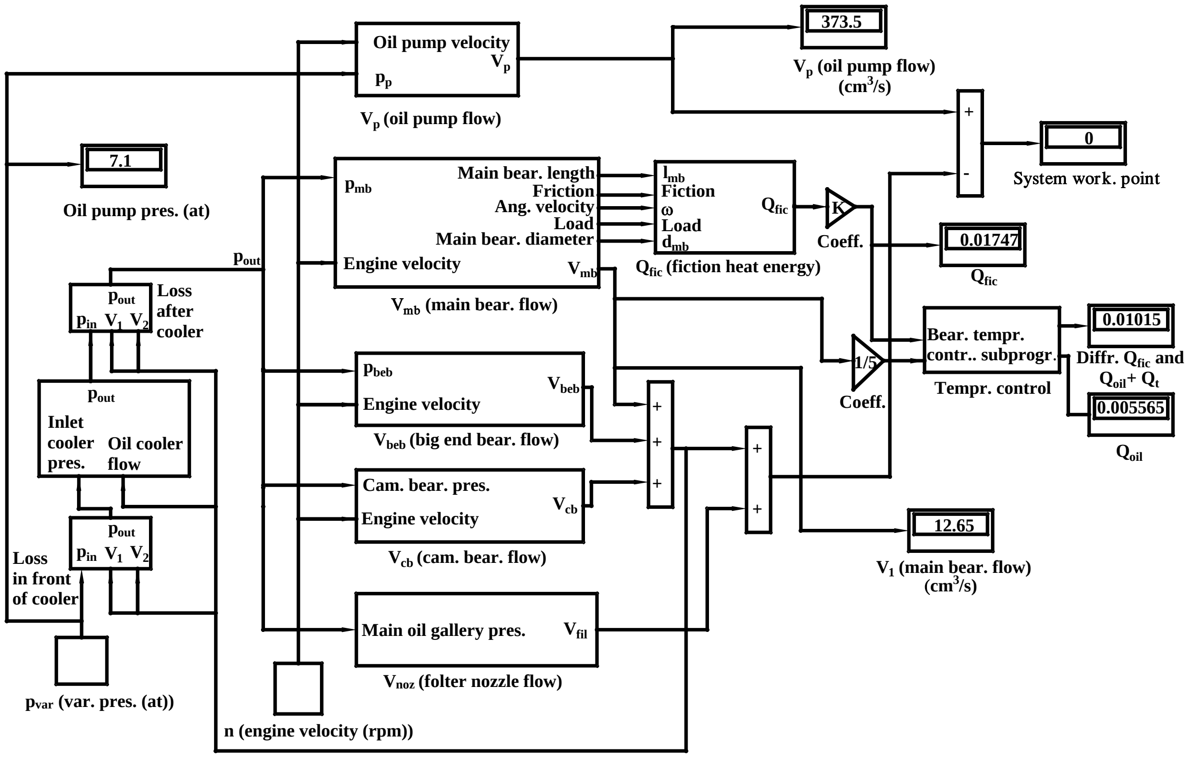

Fig. 6 General program to calculate lubrication system of diesel engine D243

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