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Individual Drive of Internal Combustion Engine Lubrication System Based on Switched Reluctance Motor

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Abstract

The article analyses the modern lubrication systems for internal combustion engines. Systems with mechanical drive components that contain mechanical and electronic components have been found to have a number of disadvantages. In particular, when the internal combustion engine is started cold, when the viscosity of the oil is high, the hydrodynamic resistance characteristic rises sharply, which leads to high pressure at low speeds and the drive requires low pump speeds. Again, the increase in oil temperature causes a decrease in viscosity, the hydrodynamic resistance characteristic becomes flatter. This, in turn, reduces the pressure in the lubrication system and requires an increase in pump speed in order to keep the pressure constant. Based on the analysis, the requirements for lubrication systems are formulated and a separate lubrication system with forced oil supply is proposed in this paper. For the drive of pump lubrication system of the internal combustion engine, a switched reluctance motor is proposed and calculated. Such motor by its qualities is one of the most useful in this type of systems.

Keywords: switched reluctance motor; lubrication pump; internal combustion engine; lubrication system; electromechanical system.

1. Introduction

Cars have a wide range of applications in different environments and different climatic conditions and are therefore exposed to loads [1]. Therefore, the technical condition of the vehicle, like any other car, during continuous operation remains unchanged. It worsens due to the wear of parts and mechanisms, failures and other faults resulting in reduced performance of the car.

The main means of reducing wear of parts and mechanisms and preventing malfunctions of the car, i.e. maintaining it in proper technical condition, is the timely and high-quality maintenance and repair, both capital and current. The technical condition also depends on the storage conditions of the car [1], [2].

Engine oil plays the same vital role in the engine as blood in the human body. No other fluid affects the internal combustion engine (ICE) operation and its service life as much as engine oil [3]. The lubrication system is designed to create a lubricating protective layer between the parts that rub, reduce wear and loss of friction power, cooling surfaces by constantly applying oil to them [3], [4], sealing gaps and removing wear products from the contact area. The lubrication system must provide [4]:

- uninterrupted supply of lubricant to the engine regardless of temperature conditions and various operation modes, on uphill and downhill, rolls;
- sufficient lubricant cleaning from mechanical impurity;
- prolonged engine operation due load without overheating;

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• simplicity of design and reliability.

This system is not perfect and has several disadvantages that affect the service life of ICE and the frequency of its repair. The first disadvantage is that during cold start of the ICE, when the oil viscosity is high - the characteristic of the hydrodynamic resistance rises sharply, which leads to high pressure at low speeds. In this mode, we need to ensure low speed of our pump to achieve the desired pressure.

A temperature increase, the oil leads to a viscosity decrease, the characteristic of the hydrodynamic resistance becomes flatter. That is, our pressure in the lubrication system decreases. To avoid this problem, increase the speed of the lubrication pump and provide the required system pressure [3], [4].

2. Study progress and results

When we analysed the operation of vehicles [1], [3], [4], we saw that the relationship between fuel loss, load and engine crankshaft speed as such does not exist. This is because under different driving conditions, such as descent and ascent, these dependencies are significantly different. For modelling processes in lubrication pump, we take into account method, which is described in [2] and as physics analogue took an internal combustion engine Mercedes-Benz OM- 602.

The pressure characteristics of the mechanical lubrication pump and the hydrodynamic resistance of the lubrication system and the pressure characteristics of the electric lubrication pump are shown in Fig.1. As we can see, the distance between points A and B, i.e. the points of nominal operation of the mechanical and electric lubrication pump is insignificant. With minimal oil viscosity at low revs, the pressure of our lubrication system is very high. Therefore, at high temperatures, our oil viscosity decreases and at low speeds the pressure of our system is low. The above-described shortcomings will allow avoiding the independent drive of lubrication electromechanical system (EMS). It will allow providing constant pressure in lubrication system irrespective of turns of the engine, oil temperature.

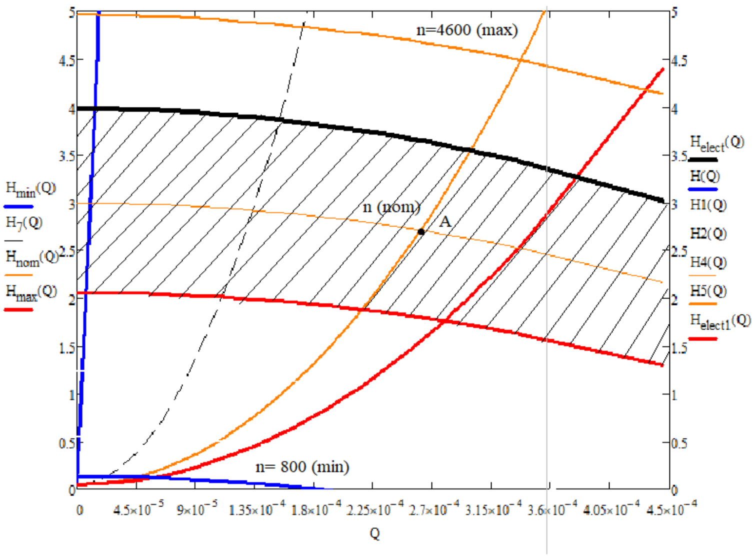

Fig.1. Pressure characteristics of the mechanical lubrication pump and hydrodynamic resistance of the lubrication system and pressure characteristics of the electromechanical lubrication pump.

Disadvantage for internal combustion engines that are equipped with a turbine is a moment when the engine temperature is maximum and it is stopped, the service life of the turbine is reduced. Some internal combustion engines install a turbo timer [3]. Its job is that at high engine temperatures, even when the ignition is off, the engine must run until the engine temperature becomes such that the turbine can be evenly cooled. For this case, we have the opportunity to program the microcontroller of our EMS. It should also be noted that at the engine's starting moment, when the ignition is turned on, before starting the starter, our EMS is already provide the set pressure in the system. Another requirement for the operation of our EMS is emergency monitoring. That is, with a critical pressure drop and high performance in the lubrication system, the electric lubrication pump is switch off.

Thus, our electromechanical lubrication system will be able to provide the required pressure and performance of the lubrication pump depending on the quality of the oil and the operating modes of ICE. Depending on the method of presenting information, EMS has the form, which is shown in Fig.2.

When the vehicle is moving uphill the load on the ICE is increased significantly and the speed of the crankshaft does not always reach the maximum value. In this mode it is necessary to provide the maximum pressure that there was no breakdown of a lubricating wedge, and also to give the maximum quantity of oil, for heat removal and cleaning of the rubbing knots.

Vehicles operational mode when the crankshaft speed is high and there is no load on the engine. This can be explained by the fact that when the car moves from the mountain, ICE consumes fuel only to ensure idling, and for modern engines at speeds above idle fuel, supply is completely blocked.

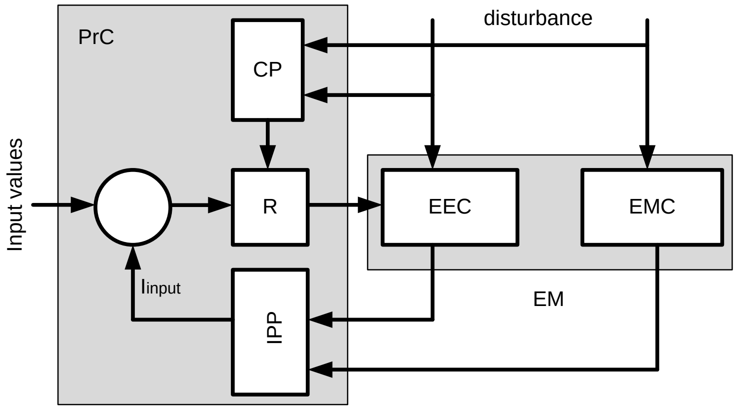

Fig.2. Structure of EMS with regulator by disturbance.

That is, in this mode there is no need to provide high pressure and performance. Our electromechanical lubrication pump can handle this task, as opposed to a mechanical lubrication pump, which is rigidly connected to the crankshaft.

Fig.2 shows that the main unit of our system is an electromechanical converter (EMC) which is controlled by electronic control (EEC), such as the electric motor. The next block of our EMS is Programming Control (PrC). It has included regulator (R) and input programing by current (IPP), which is controlled by signals from EM.

Mode when the crankshaft speed is high and there is no load on the ICE. This can be explained by the fact that when the car moves from the mountain, the engine consumes fuel only to ensure idling, and for modern engines at speeds above idle fuel, supply is completely blocked. That is, in this mode there is no need to provide high pressure and performance. Our electromechanical lubrication pump can handle this task, unlike the mechanical lubrication pump, which is rigidly connected to the crankshaft.

The EM control device can control the operation of EMS components both at the level of the principle of operation and taking into account the purpose of EMS. The structures of PrC and EM are used in EMS, which is shown in Fig.2. EMCs are separated into EMC with program control, which provides a change of the controlled coordinate according to the law, which is defined in advance and set by the program. The next one is EMC with stabilizing control, which ensures the stability of the controlled coordinate. Moreover, EMC with tracking control, which provides a change of the controlled coordinate according to a previously unknown law [1].

If the frequencies and order of switching of the EMC switches are determined depending on the location of the rotor relative to the stator, the control is referred to as closed or positional. Such control is used in a switched reluctance motor (SRM). The development of the SRM lubrication pump drive involves the motor design with optimal parameters, which would provide the appropriate torque on the shaft to overcome the starting torque of the pump.

Among a number of SRM [5], the most interesting are SRM with transistor switches [7] and RPS of various types. World practice has accumulated some experience in the production and operation of this type of motors [5]-[6]. This experience confirmed their high consumer properties, and in terms of mass production proved the economic feasibility of use in low-power drives of general use. However, SRM with PM on the rotating part of the machine have such disadvantages as the complexity of design and manufacturing technology, increased cost [5].

One of the simplest in design, one of the most technological and reliable options is an electromechanical converter with an open-pole stator and concentrated winding coils [7]. An electronic switch that connects to the DC network powers the winding. The rotor is toothed, it does not contain any winding, but its core is charged. Such EMC is simpler, cheaper than the simplest of electric machines - asynchronous, and motors on its basis on regulating properties do not concede to direct current collector motors [7]-[8]. Fig.3 shows the design of the SRM electromechanical converter with a passive rotor.

As to the requirements, specification for designing a SRM may be diverse, computer-aided design system (CADS) of SRM [8] was offered where only basic parameters such as voltage, power or mechanical moment on the shaft and shaft speed are set. The remaining independent parameters are set in dialog mode depending on other basic requirements of the vehicle [8]. To analyze the processes of creating moment, consider a structure consisting of a pair of stator teeth and a pair of rotor teeth (Fig.4).

Fig.3. EMC of SRM.

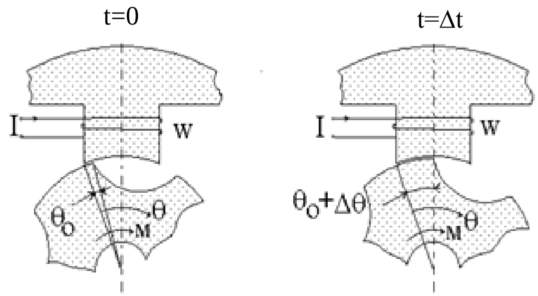

Fig.4. Moving the rotor tooth under the action of electromagnetic moment.

Insofar as a structural element interacting stator and rotor teeth are identical, we can consider only one wave interaction with a rotor and stator teeth. In time Δt the tooth will move from the position θ_0 to position $\theta_0 + \Delta\theta$. Magnetic linkage ψ is a function of rotor position θ and current *I*, thus $\psi(\theta,\mu)$. Let's assume that the current retains the value *I* during the rotor motion. The active resistance of the winding for simplicity will be considered absent. Then the work done by the power supply over time Δt can be calculated as

$$A_{source} = I \cdot U \cdot \Delta t = I \cdot |e| \cdot \Delta t = I \cdot \left(\frac{\Delta\psi}{\Delta t}\right) \cdot \Delta t = I \cdot \Delta\psi \,. \tag{1}$$

On the other hand, mechanical work, which is carried by a rotor over the time Δt, described by equation

$$A_{mech} = M \cdot \Delta\theta \,. \tag{2}$$

The increase in magnetic energy in the system when the rotor is moving can be described by the equation:

$$\Delta W_m = \int_0^{\psi+\Delta\psi} i \cdot d\psi(\theta_0 + \Delta\psi, i) - \int_0^{\psi} i \cdot d\psi(\theta_0, i) \,. \tag{3}$$

In equation (3), current varies from 0 to *I*, and a magnetic linkage ψ varies from 0 to Ψ or to $\Psi+\Delta\Psi$.

Each term of the right side of equation (3) has the following physical interpretation. The first term is the magnetic energy of the system in which the rotor is in position $\theta_0 + \Delta\theta$. Integration is carried out by a variable ψ from 0 to $\Psi+\Delta\Psi$ when $\theta = \theta_0 + \Delta\theta$. The second term is the magnetic energy of the system when the rotor is turned-on to position θ_0. Integration is carried out by a variable ψ from 0 to Ψ when $\theta = \theta_0$. Each term is integrated in parts.

The first term:

$$\int_0^{\Psi+\Delta\Psi} i \cdot d(\theta_0 + \Delta\theta, i) = I \cdot (\Psi + \Delta\Psi) - \int_0^{I} \psi(\theta_0 + \Delta\theta, i) \cdot di \,. \tag{4}$$

The second term

$$\int_0^{\Psi} i \cdot d\psi(\theta_0, i) = I \cdot \Psi - \int_0^{I} \psi(\theta_0, i) \cdot di \,. \tag{5}$$

The second term in the right-hand sides of these equations is the magnetic co-energy W_k. By substituting (4) and (5) into (3), we obtained equation

$$\Delta W_m = I \cdot \Delta\Psi - \left\{ \int_0^I \psi(\theta_0 + \Delta\theta, i) \cdot di - \int_0^I \psi(\theta_0, i) \cdot di \right\}. \tag{6}$$

Since the expression in braces is a magnetic co-energy growth, which is due to the rotor position change $\Delta\theta$, then (6) we can rewrite as follows:

$$\Delta W_m = I \cdot \Delta\Psi - \Delta\int_0^I \psi(\theta, i) \cdot di . \tag{7}$$

The first term of the right part is the power that has been defined above by (1). From here (7) we can get:

$$A_{source} = \Delta W_m + \Delta\int_0^I \psi(\theta, i) \cdot di . \tag{8}$$

Power supply operation A_{source} is spent on changing the energy of the magnetic field and on performing mechanical work:

$$A_{source} = \Delta W_m + A_{mech} . \tag{9}$$

Comparing (8) and (9) for mechanical operation A_{source} will give the below equation:

$$A_{mech} = M \cdot \Delta\theta = \Delta\int_0^I \psi(\theta, i) \cdot di . \tag{10}$$

From (10) electromagnetic torque

$$M = \frac{\Delta\int_0^I \psi(\theta, i) \cdot di}{\Delta\theta} = \left.\frac{\partial W_k}{\partial\theta}\right|_{I=Const} . \tag{11}$$

The SRM for ICE Mercedes-Benz OM-602 analogue are calculation in CADS of SRM [8]. The main characteristics of EMS on the base of SRM are given in Fig.5.

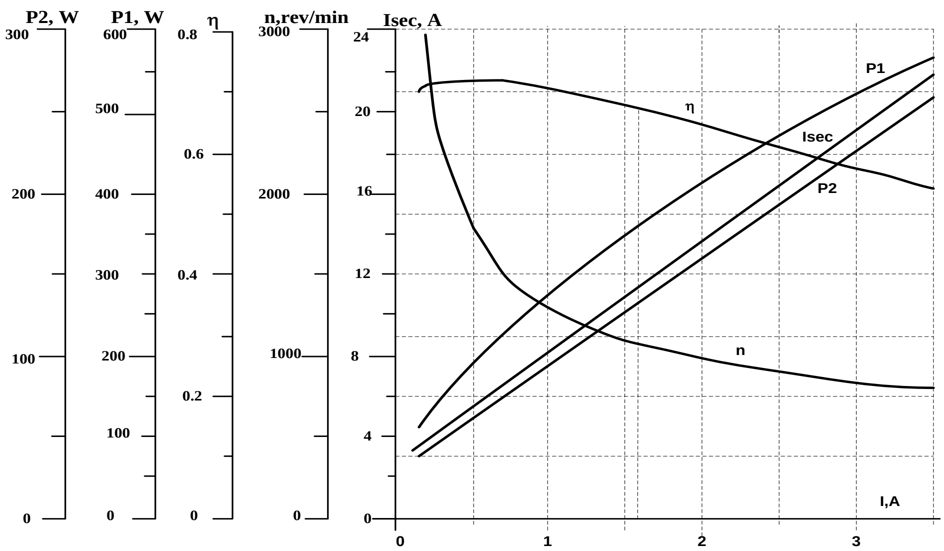

Fig.5. External characteristics of the lubrication EMS based on SRM for internal combustion engine Mercedes-Benz OM-602.

Therefore, to calculate the EMC with a passive rotor torque, it is sufficient to have an analytical expression for flux coupling as a function of current and the angle of the relative rotor and stator position. For speed control, DC-DC from 12 V/24V converter will be used.

3. Conclusion

The electromechanical lubrication system, in contrast to the mechanical system, makes it possible to create the maximum pressure in the lubrication system at significant increases in the load of the combustion engine, to prevent failure of the lubrication wedge.

It is possible to ensure the recommended pressure at idle speed of the combustion engine only with the help of an electric lubrication pump. For pump in electronic system, it is recommended to use SRM, which has a much simpler design, traces the economical and rational use of material and labour resources. In addition, SRM is much cheaper, and therefore promising and interesting for designers and developers.

Purposed lubrication EMS, allows ensuring its rational operation, in terms of energy efficiency, which is almost impossible to achieve with a mechanical lubrication pump, as it is obvious that the power consumption of an electric lubrication pump is much less than that of mechanical one. Such system allows having programming controller, receiving the necessary pressure before start of the combustion engine and will carry out function of the turbotimer after it stops.

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Індивідуальний привід системи змащування двигуна внутрішнього згорання на базі вентильного реактивного двигуна

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Анотація

У статті проведено аналіз сучасних систем змащення двигунів внутрішнього згоряння. З’ясовано, що системи з механічними компонентами приводу, що містять механічні та електронні компоненти мають ряд недоліків. Зокрема, при холодному пуску двигуна внутрішнього згорання, коли в’язкість мастила є високою, характеристика гідродинамічного опору різко піднімається вгору, що приводить до високого тиску на низьких обертах та привід вимагає низьких обертів насоса. Знову ж, зростання температури мастила є причиною зменшення в’язкості, характеристика гідродинамічного опору стає більш пологою. Це, в свою чергу, зменшує тиск в системі змащування та вимагає збільшення обертів помпи, для того, щоб підтримати тиск постійним. На основі проведеного аналізу сформульовано вимоги до мастильних систем та запропоновано окрему систему змащення з примусовою подачею мастила. Для приводу насоса системи змащування двигуна внутрішнього згорання запропоновано та розраховано вентильний реактивний двигун, який за своїми якостями є одним з перспективних щодо використання у такого типу системах.

Ключові слова: вентильний реактивний двигун; насос; двигун внутрішнього згоряння; система змащення; електромеханічна система.