ISSN 2307–3489 (Print), ISSN 2307–6666 (Online)

Наука та прогрес транспорту. Вісник Дніпропетровського національного університету залізничного транспорту, 2015, № 3 (57)

РУХОМИЙ СКЛАД І ТЯГА ПОЇЗДІВ

UDC 629.424.3.016.2:621.436.12-53

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TECHNICAL AND ENERGY PARAMETERS IMPROVEMENT OF DIESEL LOCOMOTIVES THROUGH THE INTRODUCTION OF AUTOMATED CONTROL SYSTEMS OF A DIESEL

Purpose. Today the issue, connected with diesel traction remains relevant for the majority of industrial enterprises and Ukrainian railways and diesel engine continues to be the subject of extensive research and improvements. Despite the intensive process of electrification, which accompanies Railway Transport of Ukraine the last few years, diesel traction continues to play an important role both in the main and in the industrial railway traction rolling stock. Anyway, all kinds of maneuvering and chores are for locomotives, they are improved and upgraded relentlessly and hourly. This paper is focused on finding the opportunities to improve technical and energy parameters of diesels due to the development of modern control method of the fuel equipment in the diesel engine. **Methodology.** The proposed method increases the power of locomotives diesel engines in the range of crankshaft rotation (from idle running to maximum one). It was based on approach of mixture ignition timing up to the top «dead» center of piston position. **Findings.** The paper provides a brief historical background of research in the area of operating cycle in the internal combustion engine (ICE). The factors affecting the process of mixing and its quality were analyzed. The requirements for fuel feed system in to the cylinder and the «weak points» of the process were presented. A variant of the modification the fuel pump drive, which allows approaching to the regulation of fuel feed system from the other hand and to improve it was proposed. Represents a variant of embodiment of the complex system with specification of mechanical features and control circuits. The algorithm of the system operation was presented and its impact on the performance of diesel was made. **Originality.** The angle regulating system of fuel supply allows automating the process of fuel injection advance angle into the cylinder. **Practical value.** At implementation the angle regulating system of fuel supply components of the diesel engine remain unchanged It allows installing the system on diesel engines of the existing fleet of locomotives and railroad industries. The system, considered in the modeling process, has demonstrated its desirability and feasibility of practical application for diesel engines.

Keywords: fuel; injection; combustion; camshaft; spline; stepper motor

doi: 10.15802/stp2015/46077

ISSN 2307–3489 (Print), ISSN 2307–6666 (Online)

Наука та прогрес транспорту. Вісник Дніпропетровського національного університету залізничного транспорту, 2015, № 3 (57)

Introduction

Last years in Ukraine despite the intensive process of electrification that accompanies railway transport, diesel traction continues to play an important role both in the main and industrial railway traction rolling stock [9]. Anyway, all kinds of maneuvering and chores are for locomotives, they are improved and upgraded relentlessly and hourly.

It's no a secret that the internal combustion engine is fairly long technical design. The first functional prototype was built by R. Diesel back in 1897, and the first application on the locomotive he found in 1925 year [1, 7]. As the level of science and technology is growing with impressive rapidity, it is logical that a century-old technology requires significant improvements to meet the demands at this time. As a rule, the majority of research and developments in the field of internal combustion engines is dedicated to power improvement increasing, reducing the weight and overall dimensions and lengthening the service life of machinery parts. Recently, against the background of semiconductor and computer technology development, works in the field of engine control automation have increased very significantly.

Serious research on working cycle optimizing and the design of engines were conducted in the days of tsarist Russia. Already in 1906 year V. I. Hrynevetskyi proposed a thermal calculation method of an operating cycle, the basis for the contemporary theory of processes of reciprocating internal combustion engines. Further it was developed by N. R. Brilinh, Ye. K. Masinh, B. S. Stechkin, A. S. Orlyn, N. M. Hlaholev, M. H. Kruhlov and others. In 1911 year a deep theoretical development of diesel locomotive manufacturing problems was started by V. I. Hrynevetskyi and A. N. Shelest.

Naturally, the theory of operational process gives us some concepts and ideas about operations occuring in the cylinder, and this issue has not been studied and disclosed completely, in a certain sense remains a «mystery». Air supply and fuel combustion processes play a significant role that modern engineering tries to make utmost as much complete and energy saving as possible.

For a complete fuel and air mixing, filling the combustion chamber, it is necessary to provide such kinetic energy with dropwise at which they will not be concentrated near the injection spray nozzle, but won't reach neither the walls of cylinder cover nor piston bottom [10]. Drops of fuel mass are concentrated in the vicinity of the nozzle and due to the lack of oxygen are not burnt completely. With the weight drops increase its range capability is growing. It can lead to the fuel ingress on the cooled walls of a cylinder or excessively heated piston bottom. In the first case, the fuel does not burn and mixes with oil, in the second one it evaporates quickly when the lack of oxygen. As the result there is a coke.

Thus for perfect fuel combustion in diesel engines, it is necessary to generate fuel contact with air in the cylinder center and obtain simultaneously a sufficient velocity of the fuel particles relative to air. The latter condition is necessary in order that combustion products, formed near the fuel particles, have to be replaced rapidly by air. That is why in diesel engines for good performances of combustion, air surplus is introduced, compared with theoretically calculated one. The value of the air surplus coefficient typically is in the range of 1.5…2.0 [1, 7]. In addition, the transition to a modification of cylinder covers with vortex chambers could enhance the expected effect significantly.

It's not a secret that the effective operation of diesel depends both on timely full air supply and correct fuel supply to the cylinder. Obviously, it means rational injection taking into account dispersion of fuel particles and the process velocity and timely fuel supply to the nozzle. Requirements are as following [2]:

a) fuel supply about 5…30° till t.d.c. (top dead center), (depending on a diesel);

b) injection duration not less than 20…45° of the crank spin;

c) cyclic fuel supply should meet the speed range and load operation mode of the diesel [9].

Currently there is no system on the locomotive ICE that made it possible to control parameters such as the law of supply and the real advance angle of fuel supply.

The first is determined by the profile of the camshaft lobe, throat area of an injector nozzle and some other design parameters. The second indicator is measured in degrees of crankshaft rotation from the start of the diesel fuel injection to t.d.c. and it is a little leeway, which gives fuel to

doi: 10.15802/stp2015/46077

form a mixture of work and fully erupt in a matter of a second. Such procedure is necessary due to the fact that the processes time in the cylinder is extremely small, and for ignition of fuel this time, anyway required.

It is obvious that setting fuel injection advance angle is a static index, which can not be corrected during the diesel operation [8, 10]. And this is connected primarily with the following act: a camshaft lobe moves to the roller-pusher of a fuel pump at the same time. At this, it should be remembered that the rate of operating cycles with speed-up increases and the time required for fuel to realize the above mentioned reactions is not changed. At first sight, the problem can be solved by setting the highest possible fuel injection advance angle but it is not its decision. Insufficient angle on high positions leads to incomplete combustion of fuel, which tends to flow along the walls of the cylinder bushing, to thin out the oil and cause a dry or semi-dry friction with all consequences that entails. Excessive angle at low positions leads to increased detonation phenomena during the power stroke and the diesel knock. It is not useful for the crank mechanism and valves, as leads to increased tension in them [8, 10].

Unfortunately, in today's constructive building of locomotive diesel engines, this possibility directly tied to changes in design of fuel injection pump linkage [3, 6].

Purpose

Search enhancement the technical and energy parameters of locomotives through the modern methods introduction of diesel fuel equipment.

Methodology

However, let us consider the alternate solution of this question with a possible design system execution that offers a complete combination of two subsystems: the mechanical (executive) and electricity (controlling).

Mechanical part of the automated control system of fuel injection advance angle (further – SAC FIAA) is a set of devices, which form a single chain (Fig. 1). The most characteristic feature is that the solid camshaft of fuel injection pump linkage that is substituted on combined one, consists of two components: an external cam shaft 1 and inner splined shaft 2. The camshaft is hollow and has interior straight-sided splines, whereby the inner shaft is movable in it in the axial direction in both sides (like a cardan shaft). Internal splined shaft is double and consists of two shafts of the same diameter, connected from the face with friction clutch. The part that engages with the camshaft has the usual straight-sided splines, and the other one has splines that are cut at an angle. They mesh with the same oblique splines of a driven gear 3 in the camshaft, which are cut on the inner surface of the slot in its hub.

It is thus evident, the oil-pump drive gear, unlike the classic design, floating motionless. Since at the axial movement of the internal shaft, friction forces are arising between the splines that are trying to shift a gear up and disengaged, split locking bushing 4 is set, which prevents this undesirable effect. The bushing is attached to the block of a diesel engine and has a layer of antifriction material spraying on the internal operating surfaces in order to mitigate friction between it and the gear. The inner splined shaft is ended with a pivot to set a bearing 5. There is a conical roller thrust and radial bearing, as at operation it perceives axial loads mainly. With the outer ring the bearing is pressed into a special cage 6, which is performed together with the tooth rack 7 and forms with it a single link mechanism. The tooth rack is meshed with the toothed wheel 8, which has involute tooth profile (like a rack itself). This wheel is located on the same shaft 9 with the wormwheel 10, which is actuates by a cylindrical worm 11 and spindled on the motor shaft 12. This is control element of the entire system and operates in the «start-stop» mode.

The electric motor that controls operation of the circuit is not an ordinary one. In our case, the stepping motor is used, which is widely used in automatic control systems, particularly in CNC (computer numerical control) machines. On the engine column top there is a synchro transmitter 13, which is connected with the motor by means of a belt driving 14, the gear ratio is 1: 1. This electric machine is used in the electrical subsystem as a part of the sensor feedback.

In the dynamic state the system operates as follows. When switching the controller of a driver to the next position, the crankshaft rotation frequency of the the diesel engine increases.

doi: 10.15802/stp2015/46077

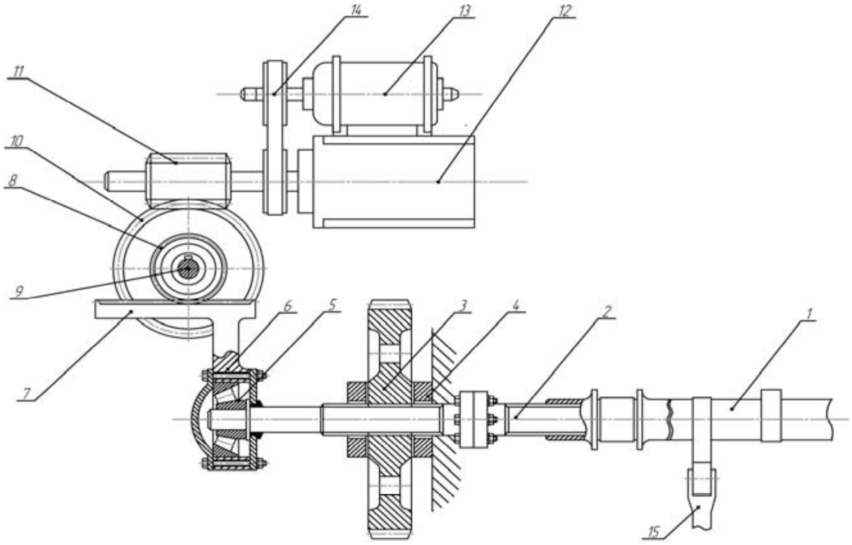

Fig. 1. General view of mechanical subsystems of the automated control of the fuel injection advance angle

The stepper motor (SM) receives a signal from the control system and returns through the worm, wormwheel and therefore the tooth one with it. Tooth wheel causes linear movement of the tooth rack, and hence the internal splined shaft. Passing trough oblique splines in the driven gear at a certain fixed distance, the shaft is rotated together with the camshaft at a specific angle in the direction of the cam climbing delay against the fuel-pump tappet 15 and thereby increases the lead angle of the fuel supply for a certain amount. The entire process takes place directly during rotation of the composite shaft and does not affect its performance adversely. With decreasing the position of a driver's controller, the system begins to operate in a similar manner, but with the difference that the SM runs backwards. The motor shaft together with the worm begins to rotate in the opposite direction and the combined shaft will rotate to a certain angle in the direction of acceleration of cam climbing on the fuel-pump tappet.

Special focus is on electrical part of the system (Fig.2). The complex of electrical and electronic devices is aimed at operation management of the above mentioned SM. The first element in the circuit is dynamoelectric engine speed sensor namely this is a tachometer generator (TG), the shaft of which is mechanically connected to the crankshaft of a diesel engine and realizes an electric signal proportional to the diesel speed.

The generated voltage is supplied to the electronic controller, which is a series of semiconductor devices: signal converter (SC), the generator (former) of pulses (GI), a distributor of pulses (DI), the pulse counter (PC), the control unit (CU). After the conversion, tacho voltage is supplied through the transistor amplifier (TA) to SM power supply. Feedback is provided in the circuit with pair of synchros working in transformer mode.

Now having understood the structure of the system, one can determine the algorithm of its operation. When switching the position of the driver's controller to the next one, crankshaft diesel speed increases, and with it – the TG shaft. The voltage on its terminals increases, and then the controller comes into action. SC converts the received voltage into a pulse form and transmits it to the GI, which brings the number of pulses and their amplitude to the value that is necessary for SM power supply. Further, the voltage pulses are transmitted to the DI, which acts as a switch windings, and then – on the TA. After amplification, the pulses fall at last in winding phase of SM. One pulse causes the angular displacement of the rotor by one step. For the rotor cranking at a certain angle, one need a sequence of pulses, which is determined by the number of switching intervals (the position of the driver's controller) with the output angle of the shaft in the SM in one step and with the parameters of mechanical subsystem SAC FIAA.

doi: 10.15802/stp2015/46077

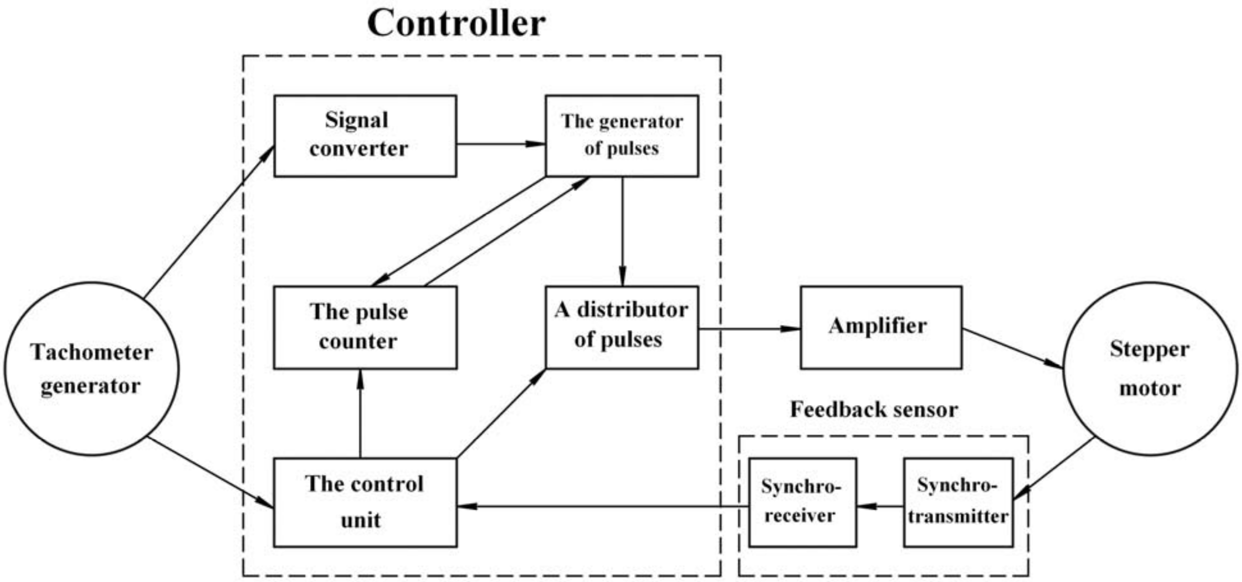

Fig. 2. Management subsystems of the automated control of the fuel injection advance angle

For the research was chosen a diesel K6S310DR, locomotive CHME3. The diesel is four-stroke, six-cylinder with turbocharging air. The simulation [11] in the software package Diesel RK, has shown that a reduction of FIAA to value lower 16º r.c.s. (crank-shaft roll) is unreasonable, since there is a significant power loss and fuel consumption increase, so the main calculations are performed in the range of 17…24º r.c.s. (maximum value of 24 is recommended for this type of diesel engine) [13, 14]. The calculation results are shown in Table 1 and Table 2. There is also an opportunity to evaluate the technical and economic performances of the diesel model [5].

On the basis of tabular data, one can construct graphic dependences for clarity.

Table 1

Diesel indicators with unregulated fuel injection advance angle

n_{rot}, min^{-1}	N_e, кW	P_i, MPa	b_i, kg/kW h	NO_x, g/kW h	PM, g/kW h
350	540	1,257	0,218	7,9	0,442
380	585	1,255	0,222	6,8	0,56
420	647	1,261	0,222	6,6	0,566
460	705	1,258	0,224	6,3	0,597

End of table 1

n_{rot}, min^{-1}	N_e, кW	P_i, MPa	b_i, kg/kW h	NO_x, g/kW h	PM, g/kW h
510	777	1,256	0,229	5,7	0,694
560	825	1,225	0,238	4,9	0,833
660	861	1,114	0,269	3,4	1,299
750	938	1,09	0,279	3,1	1,416

Table 2

Diesel indicators with regulated fuel injection advance angle

N_{rot}, min^{-1}	Ne, kW	Pi, MPa	bi, kg/kW h	NO_x, g/kW h	PM, g/kW h
350	542	1,255	0,218	7,7	0,442
380	587	1,255	0,222	6,8	0,559
420	649	1,264	0,222	6,8	0,537
460	710	1,264	0,222	6,5	0,539
510	785	1,271	0,226	6,1	0,59
560	840	1,243	0,233	5,3	0,69
660	902	1,145	0,26	4,1	1,044
750	995	1,133	0,267	3,8	1,1

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The curves in Fig. 3, 4, 5, 6, 7 demonstrate how technical and economic, environmental indicators are changed in the application of the investigated diesel at SAC FIAA application.

Findings

As can be seen, indexes are quite optimistic. Average indicated pressure increases due to maximum combustion pressure increase, and this in turn leads to an increase the power of diesel effectiveness and reduction the specific fuel consumption. This is especially expressed in the second half of the speed range of diesel performance [12]. Unfortunately, there are negative aspects of this regulation. One can observe increase of nitrogen oxides emissions in exhaust gases, which nevertheless tends to decrease with increasing in shaft speed diesel [13, 14]. These compounds, on the level of carbon monoxide and sulfur oxides, are one of the most harmful impurities in the exhaust gases, so from an environmental point of view this is an undesirable effect.

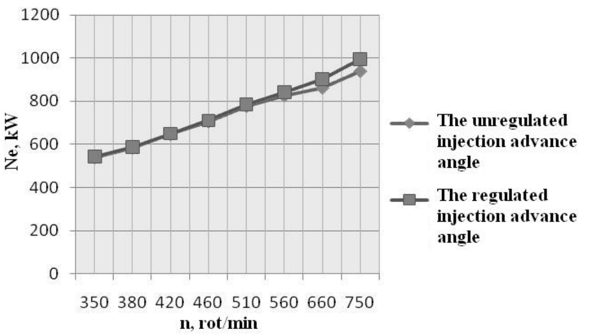

Fig. 3. Comparison of effective power

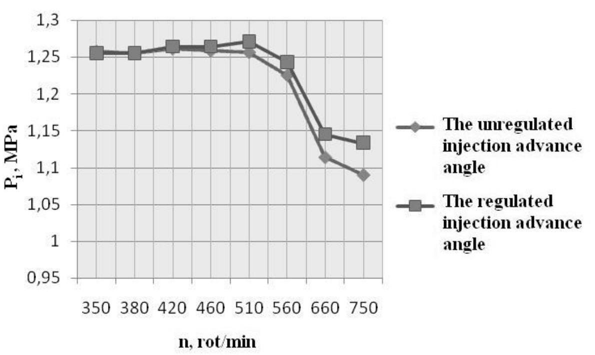

Fig. 4. Comparison of average indicated pressure in the cylinder

At the same time, the content of soot particles is reduced quite significantly, which is certainly is a positive difference.

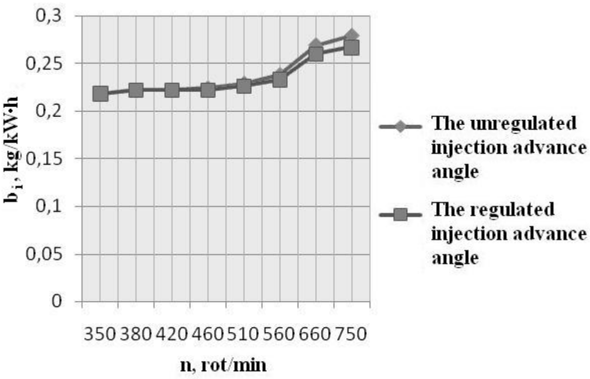

Fig. 5. Comparison of specific fuel consumption of a diesel

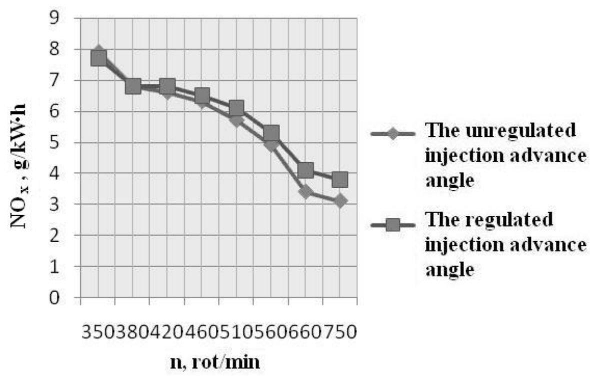

Fig. 6. Comparison of the nitrogen oxides content in the exhaust gases

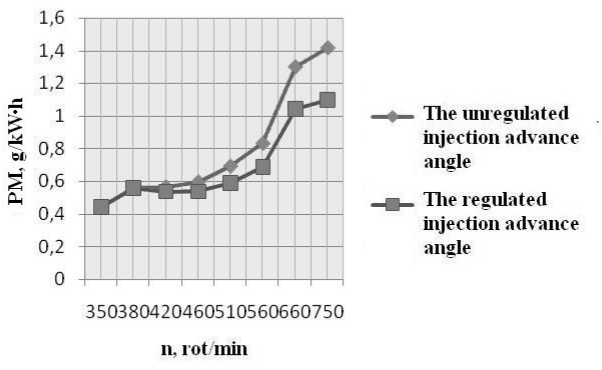

Fig. 7. Comparison of soot content in the exhaust gases

doi: 10.15802/stp2015/46077

The ability to control the timing of fuel injection advance angle at the operation of the diesel engine, could make a significant contribution to the improvement of the workflow. Thus, it is possible to achieve a rational, but not excessive pressure combustion in all positions of the controller. And combining the proposed system using the eddy combustion chambers, one can achieve a better combustion, higher capacity, improving the environmental performances of the diesel engine and the technical state of the cylinder-piston group.

Originality and practical value

The adjust system of the fuel supply angle allows automating the process of selecting the fuel injection advance angle into the cylinder directly at diesel engine operation. Thus diesel engine components remain unchanged, except the countershaft, which can be upgraded in depot repair production [9]. This allows installing the system on the diesel engine of existing railway locomotives fleet and industry enterprises.

Conclusions

Discussed above system at the simulation, has demonstrated its feasibility and possibility of practical application in locomotive ICE. Mathematical calculation showed an increase in the effective power to 2.2%, reducing fuel consumption to 1.6% and improvement of environmental performance. Implementation the automated control system of fuel injection advance angle makes it possible to improve technical and energy parameters of the locomotive as a whole.

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doi: 10.15802/stp2015/46077

ISSN 2307–3489 (Print), ISSN 2307–6666 (Online)

Наука та прогрес транспорту. Вісник Дніпропетровського національного університету залізничного транспорту, 2015, № 3 (57)

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ПОЛІПШЕННЯ ТЕХНІКО-ЕНЕРГЕТИЧНИХ ПАРАМЕТРІВ ТЕПЛОВОЗІВ ЗА РАХУНОК ВПРОВАДЖЕННЯ АВТОМАТИЗОВАНИХ СИСТЕМ КЕРУВАННЯ ДИЗЕЛЕМ

Мета. На сьогоднішній день питання щодо тепловозної тяги залишається актуальним на більшості промислових підприємств та залізниць України, а тепловозний дизельний двигун продовжує бути об’єктом всебічних досліджень і вдосконалень. Не зважаючи на інтенсивний процес електрифікації, який супроводжує залізничний транспорт України останні роки, тепловозна тяга продовжує відігравати важливу роль як в магістральному, так і в промисловому залізничному тяговому рухомому складі. Так чи інакше, всі види маневрових та господарських робіт залишаються за тепловозами, які невпинно й повсякчасно удосконалюються й модернізуються. Робота спрямоване на пошук можливості поліпшення техніко-енергетичних параметрів тепловозів за рахунок розробки сучасного методу регулювання роботи паливної апаратури дизельного двигуна. **Методика.** Використано запропоновану методику підвищення потужності тепловозних дизельних двигунів у діапазоні частот обертання колінчастого валу (від холостого ходу – до максимального), в основу якої покладено наближення моменту запалювання суміші до верхньої «мертвої» точки положення поршня. **Результати.** В роботі наведена коротка історична довідка наукових досліджень в області робочого циклу двигунів внутрішнього згорання (ДВЗ). Проаналізовані чинники, які впливають на процес сумішеутворення та його якість. Приведені вимоги до подачі пального в циліндр та «слабкі місця» цього процесу. Запропонований варіант модернізації приводу паливних насосів, який дозволяє підійти до регулювання паливоподачі з іншого боку та покращити його. Представлений варіант конструктивного виконання комплексної системи з уточненням механічних особливостей та схеми управління. Наведений алгоритм роботи системи та зроблена оцінка його впливу на параметри роботи дизеля. **Наукова новизна.** Запропонована система регулювання кута подачі палива, яка дає змогу автоматизувати процес вибору кута випередження подачі палива в циліндр. **Практична значимість.** Складові частини дизельного двигуна при впровадженні системи регулювання кута подачі палива залишаються без змін, що дозволяє встановлювати систему на дизелі наявного парку тепловозів залізниць та промислових підприємств. Розглянута система в ході моделювання показала свою доцільність та можливість практичного застосування на тепловозних дизелях.

Ключові слова: паливо; впорскування; згорання; розподільчий вал; шліци; кроковий двигун

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doi: 10.15802/stp2015/46077

ISSN 2307–3489 (Print), ISSN 2307–6666 (Online)

Наука та прогрес транспорту. Вісник Дніпропетровського
національного університету залізничного транспорту, 2015, № 3 (57)

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УЛУЧШЕНИЕ ТЕХНИКО-ЭНЕРГЕТИЧЕСКИХ ПАРАМЕТРОВ ТЕПЛОВОЗА ЗА СЧЕТ ВНЕДРЕНИЯ АВТОМАТИЗИРОВАННЫХ СИСТЕМ УПРАВЛЕНИЯ ДИЗЕЛЕМ

Цель. На сегодняшний день вопрос, связанный с тепловозной тягой, остается актуальным на большинстве промышленных предприятий и железных дорог Украины, а тепловозный дизельный двигатель продолжает быть объектом всесторонних исследований и усовершенствований. Несмотря на интенсивный процесс электрификации, который сопровождает железнодорожный транспорт Украины последние годы, тепловозная тяга продолжает играть важную роль как в магистральном, так и в промышленном железнодорожном тяговом подвижном составе. Так или иначе, все виды маневровых и хозяйственных работ остаются за тепловозами, которые неустанно и ежечасно совершенствуются и модернизируются. Работа направлена на поиск возможности улучшения технико-энергетических параметров тепловозов за счет разработки современного метода регулирования работы топливной аппаратуры дизельного двигателя. **Методика.** Использована предложенная методика повышения мощности тепловозных дизельных двигателей в диапазоне частот вращения коленчатого вала (от холостого хода − до максимального), в основу которой положено приближение момента зажигания смеси в верхней «мертвой» точке положения поршня. **Результаты.** В работе приведена краткая историческая справка научных исследований в области рабочего цикла двигателей внутреннего сгорания (ДВС). Проанализированы факторы, которые влияют на процесс смесеобразования и его качество. Приведены требования к подаче топлива в цилиндр и «слабые места» этого процесса. Предложен вариант модернизации привода топливных насосов, который позволяет подойти к регулированию топливоподачи с другой стороны и улучшить её. Представлен вариант конструктивного исполнения комплексной системы с уточнением механических особенностей и схемы управления. Приведен алгоритм работы системы и сделана оценка его влияния на параметры работы дизеля. **Научная новизна.** Предлагаемая система регулирования угла подачи топлива позволяет автоматизировать процесс выбора угла опережения подачи топлива в цилиндр. **Практическая значимость.** Составные части дизельного двигателя при внедрении системы регулирования угла подачи топлива остаются без изменений, что позволяет устанавливать систему на дизели имеющегося парка тепловозов железных дорог и промышленных предприятий. Рассмотренная система в ходе моделирования показала свою целесообразность и возможность практического применения на тепловозных дизелях.

Ключевые слова: топливо; впрыск; сгорание; распределительный вал; шлицы; шаговый двигатель

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doi: 10.15802/stp2015/46077

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Received: Jan. 15, 2015
Accepted: March 16, 2015

doi: 10.15802/stp2015/46077