Department of Internal Combustion Engines

Substantiation of the method of disconnection of cylinders of the stationary diesel generator in the range of operational loadings

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ACTUALITY OF THE PROBLEM

Diesel generators 7D100M produced by Malyshev plant (figure 1.1) are widely used in Ukraine and on the territory of the former Soviet Union countries:

- at mini power plants;
- agricultural and industrial enterprises;
- Utility;
- military facilities etc. .

These engines are a modification of 2D100 diesel diesels.

ACTUALITY OF THE PROBLEM

Diesel 7D100M operating parameters

Power, (kW)	1100
Crankshaft speed, (min^{-1})	750
Number of cylinders	10
Bore (mm)	207
Stroke (mm)	2x254
Compression ratio	15,1
Working order of the cylinders	1-6-10-2-4-9-5-3-7-8
Mean effective pressure, bar	5,32
Maximum combustion pressure, (MPa)	8,8
Efficiency: effective indicated mechanical	 0,36 0,45 0,8
Fuel/air equivalence ratio summary in the cylinder	 2,6 1,9
indicated pressure, (kg / sm^2)	1,26
Specific fuel consumption, (g / kWh)	$231{,}2^{+5}$
Specific consumption of oil for burning, (g / kWh)	1,36
Specific oil consumption total (g / kWh)	4,08
Resource to overhaul, (time)	40 000

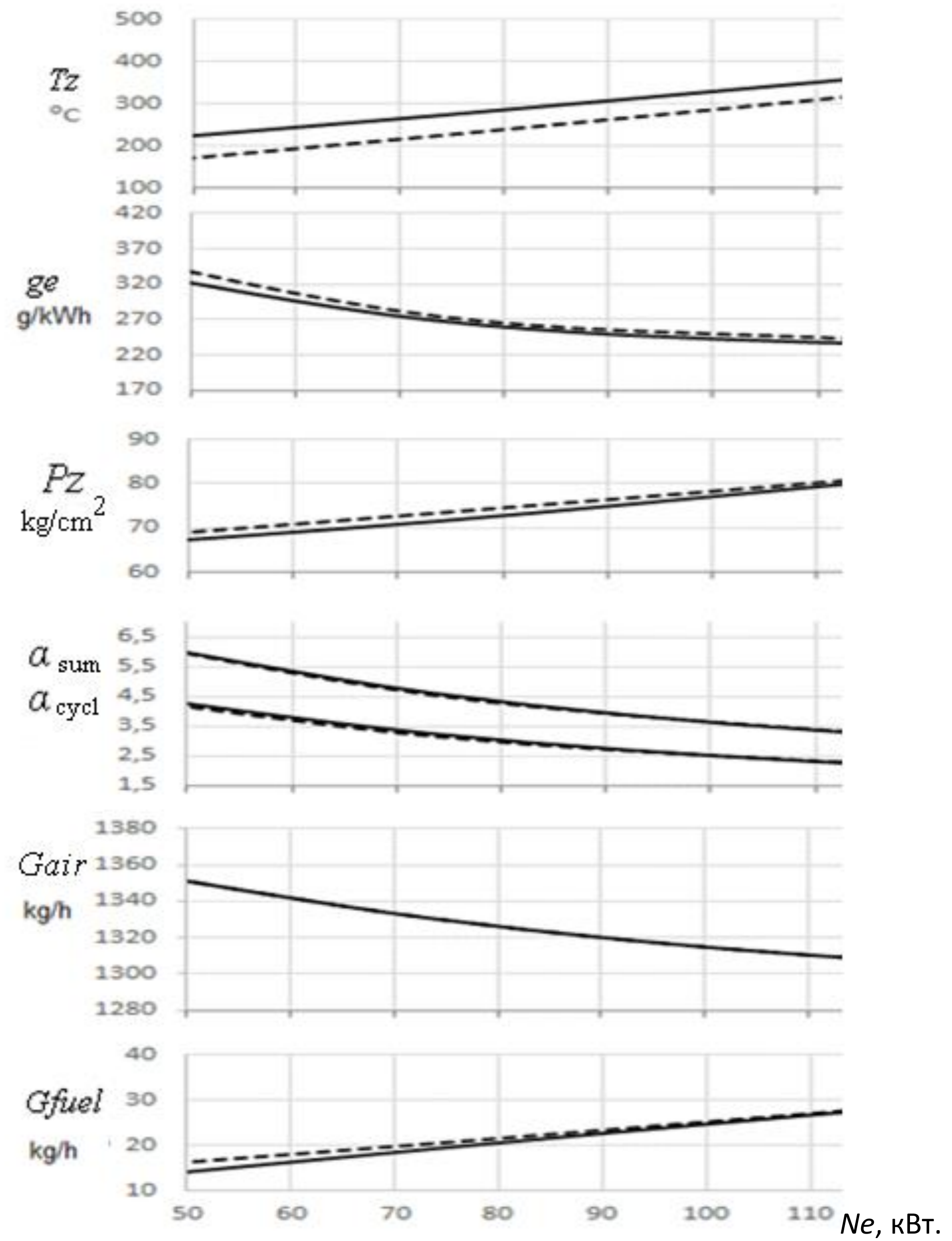
ACTUALITY OF THE PROBLEM

Diesel 2D100 load operating characteristics (compartment parameters) :

——— - experimental results for OD100 compartment; - - - – calculated results for diesel 2D100.

With decreasing the load on the engine due to the reduction of the cyclic fuel supply, the fuel/air equivalence ratio in the cylinder increases from 1.9 in nominal mode to 4.9 in the mode of 25% Ne. The maximum cycle pressure decreases from 8.8 to 6.8 (MPa), and the temperature of the exhaust gases is reduced from 480 to 210 (C°).

The reason for the change in engine power is related to the electric current consumption from the engine-generator (for example, at different times of the day, or the number of driven devices used). As a result, the quality of the mixture formation in the cylinder deteriorates, the maximum temperature in the cycle and the thermal efficiency decrease, the specific fuel efficiency is significantly increased from 231.2 (g / kWh) to 330 (g / kWh).



IMPROVEMENT OF ENGINE PARAMETERS BY CYLINDERS DEACTIVATION

One of the effective ways to improve the performance of diesel engines in low load and idle modes is the use of **cylinders deactivation** or by **deactivating individual cycles**

This method allows to increase the maximum combustion pressure, the indicator efficiency, the quality and completeness of combustion in the "working" cylinders and in this way to improve efficiency of the whole engine at low and middle loads.

Currently, there are the following methods of regulating the engine by changing its working volume: disconnection of individual cylinders or groups of cylinders, the creation of a "stretched" order of operation by deactivating individual cycles, providing partial mode by dispersal-runoffs near a given rotational speed and other.

The best prospects are the deactivation of individual cylinders or groups of cylinders.

PROBLEMS OF MAKING THE ALGORITHM OF CYLINDERS DEACTIVATION

Despite the widespread use of the method of deactivation individual cylinders (or groups of cylinders) on modern engines, today in the literature insufficiently considered methodological aspects of this problem:

- The technique (or methodology) of making the algorithm of cylinders deactivation is not described in open literature;
- It is not quite clear by what criteria the maximum engine power is limited when diesel is running with deactivated cylinders;
- how the operating speed range is selected when the cylinders are deactivated;
- How to determine the effectiveness of an algorithm for cylinders deactivation .

This determines the relevance of the topic of scientific work.

THE PURPOSE AND OBJECTIVES OF THE STUDY

The **purpose** of this work is to develop a method of algorithm formation for a diesel engine 7D100M cylinders deactivation taking into account a set of criteria of efficiency and limitations**.**

In order to achieve this goal, it is necessary to solve the next **tasks**:

1. The effect of cylinder deactivation on engine operating parameters exploration.

2. The effect of cylinder deactivation on the dynamics of the crank gear exploration.

3. Criteria and limitations proposition when choosing a rational cylinder deactivation algorithm.

4. Cylinder deactivation algorithms development and engine performance at the use of the proposed algorithms.

5. Cylinder deactivation system design.

6. Fuel supply to the cylinder calculation

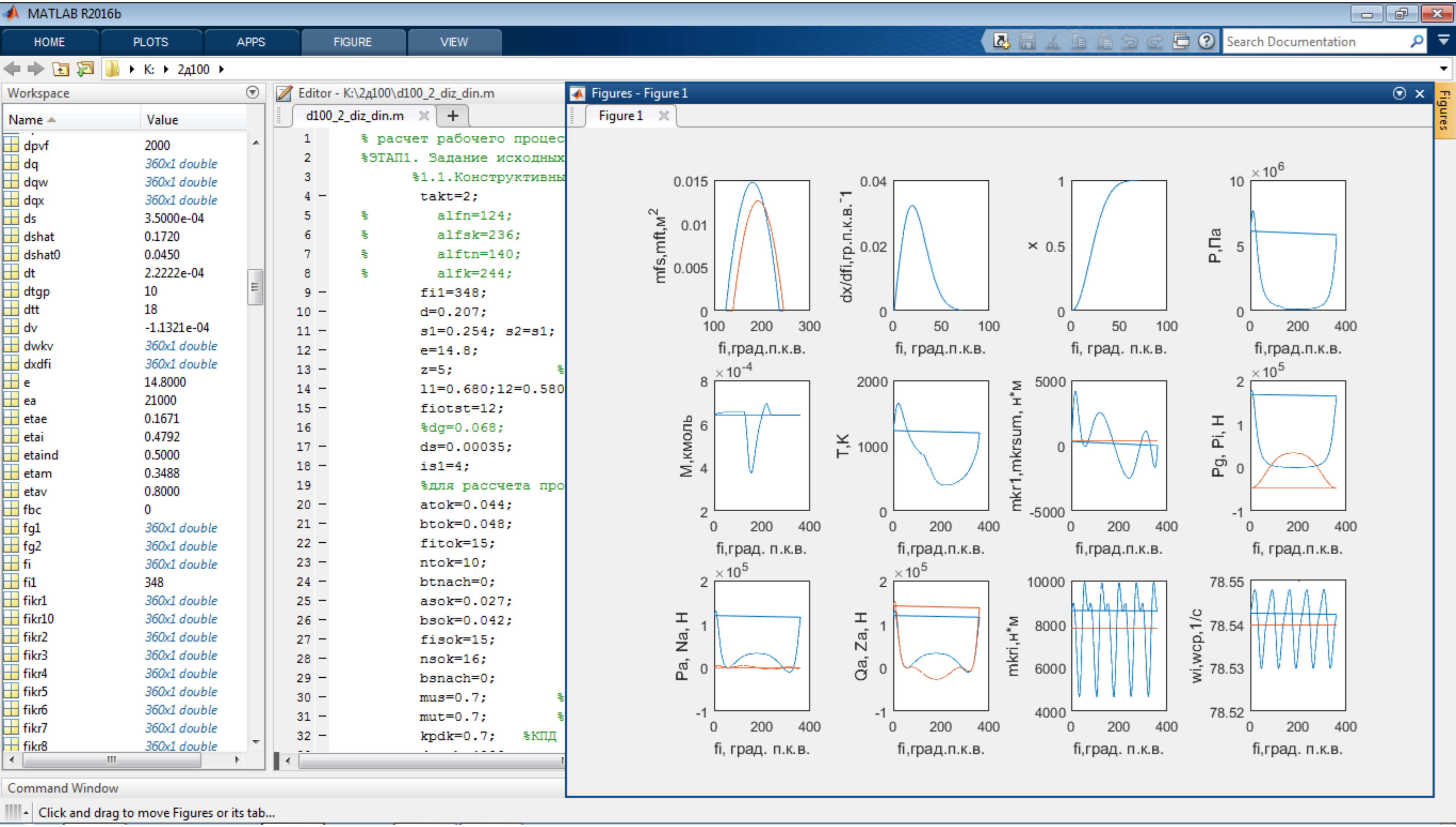
7. Technical and economic grounding

8. Environmental and civil protection

FEATURES OF MATHEMATICAL MODEL OF STATIONARY DIESEL GENERATOR OPERATING PARAMETRS

- ✓ the model allows to determine the thermophysical properties of diesel fuel components and combustion products;
- ✓the mathematical model of the working engine is quasi-stationary;
- ✓Thermodynamic in-cylinder model based on of the first law of thermodynamics, the law of mass conservation and the state equations;
- ✓ In heat transfer model, the amount of heat transferred to the wall was determined by the well-known Newton-Richman equation. Heat transfer coefficient for the 7D100M engine was determined by *Gerhard Woschni* equation;
- ✓ Mathematical modelling of combustion process was carried out on the basis of Wiebe model , coefficients of the Wiebe function are obtained by processing of experimental pressure diagrams. Empirical equations for their determination were obtained.

WINDOWS WITH THE MATLAB PROGRAM AND RESULTS OF CALCULATION

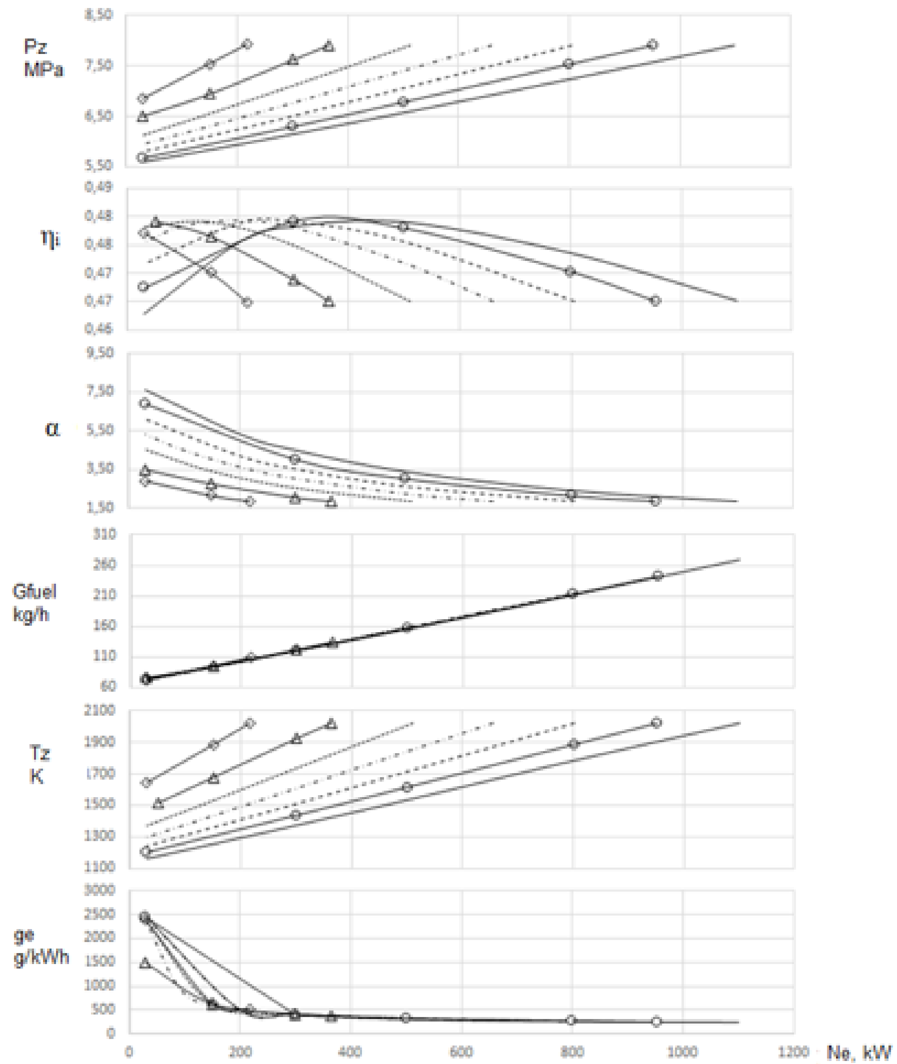


ANALYSIS OF THE ENGINE WORKFLOW WHEN DISCONNECTING INDIVIDUAL CYLINDERS OR CYCLES

At a certain loading mode there is a rational number of deactivated cylinders that provides growth of indicator efficiency of the engine.

When more or less number of cylinders are deactivated relatively to the rational number it leads to deterioration of the indicator process.

Thus, this parameter (**indicator efficiency**) can be taken as the **main criterion (objective function)**, which determines the number of operating and deactivated cylinders



—— – 10 cylinders; ○ – 9 cylinders; - - - - – 8 cylinders; –.–.– 7 cylinders; ...... – 6 cylinders; △ – 5 cylinders; ◆ – 4 cylinders.

Figure 2.10 - Diesel 7D100M load operating characteristics ($n = 750\ min^{-1}$).

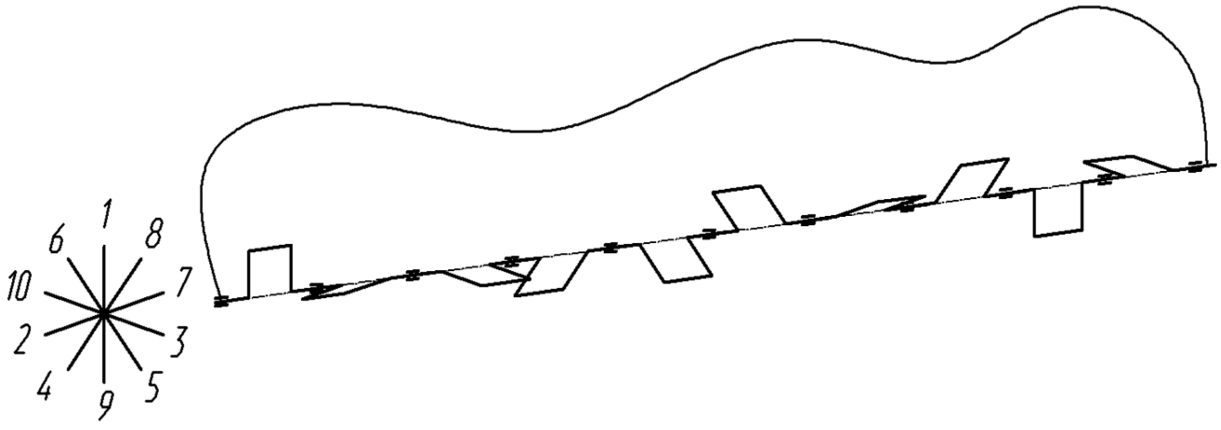
ANALYSIS OF THE ENGINE WORKFLOW WHEN DISCONNECTING INDIVIDUAL CYLINDERS OR CYCLES

Reducing the air/fuel equivalence ratio in the "working" cylinders leads to an increase in the maximum pressure in the combustion chamber.

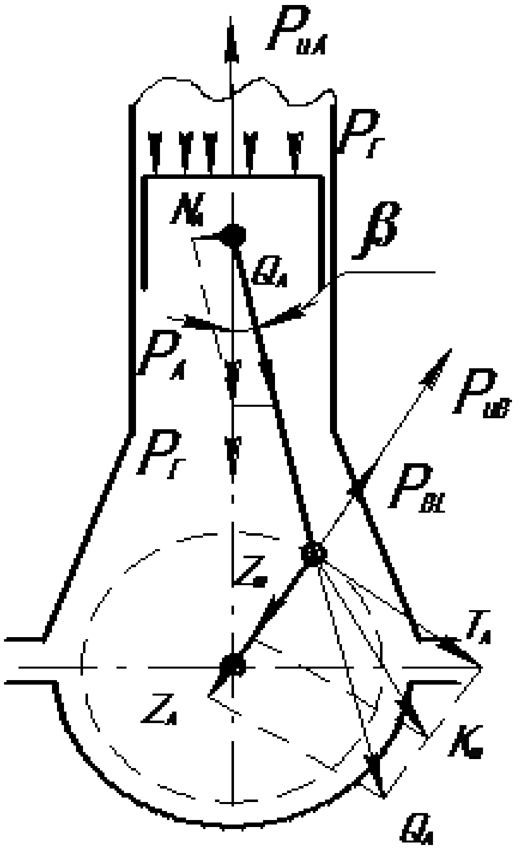
The increase in the maximum combustion pressure leads to an increase in the loads on the engine components and to a reduction of their reliability, which limits the maximum engine power. Therefore, when creating a cylinder deactivation algorithm, the **increase of the maximum combustion pressure as a limiting criterion should be taken into account.**

In section 1, it is shown that the deactivating of cylinders leads to an increase in the interval between flashes in engine cylinders, which causes an **increase in torque and torque unevenness and**, as a consequence, vibration of the engine and the installation as a whole. The next section of the work is devoted to determining these parameters..

RESULTS OF THE LOWER CRANKSHAFT DYNAMIC CALCULATION



Scheme of the lower crank gear



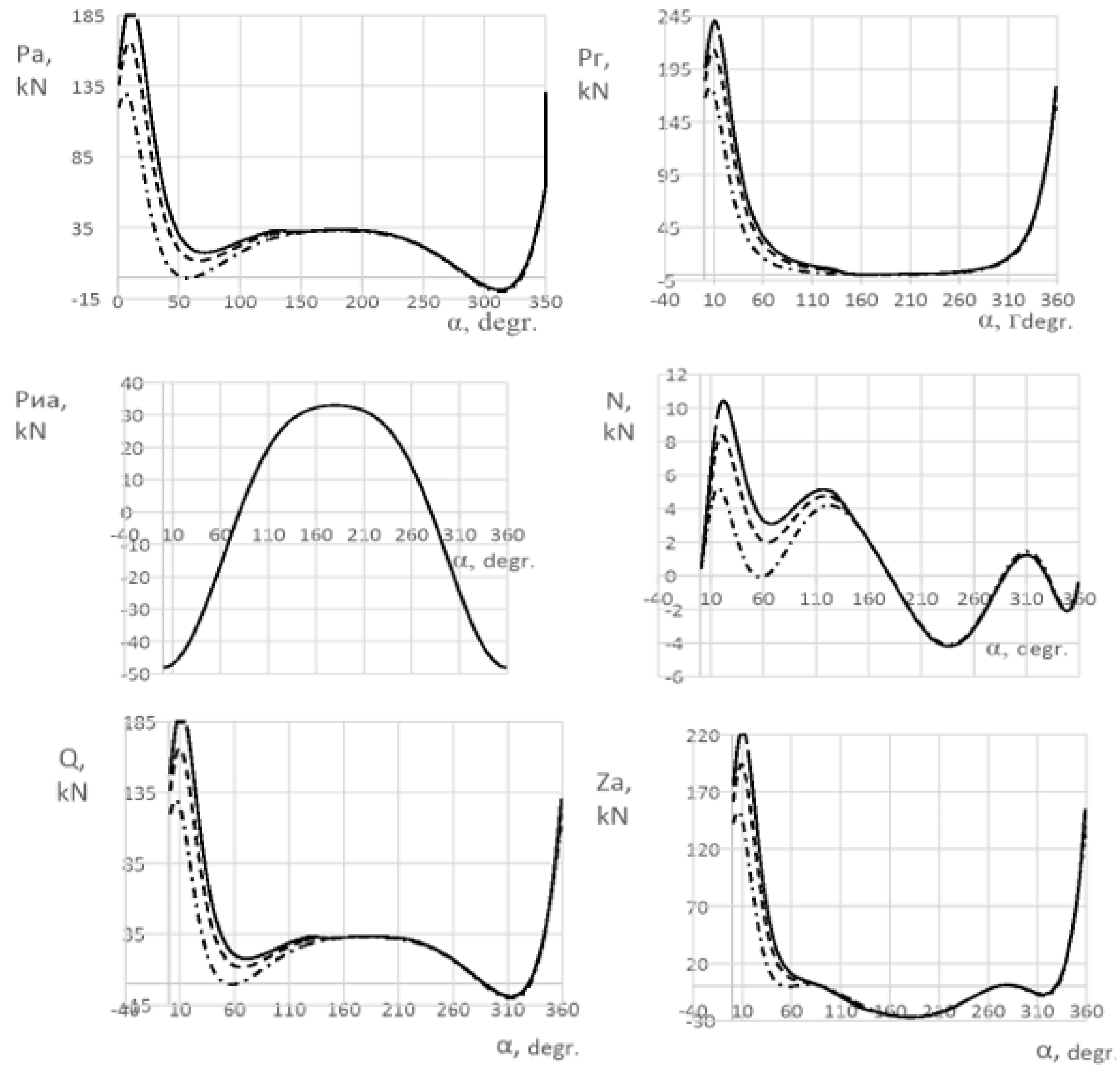
Scheme of forces acting in the lower crank gear

RESULTS OF THE LOWER CRANKSHAFT DYNAMIC CALCULATION

The value of forces in the engine compartment crank mechanism in the mode of Ne = 200kW:

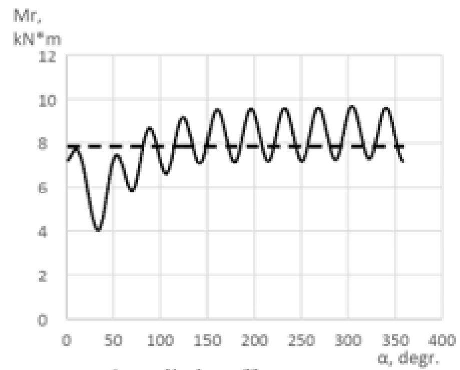
- - - - - base engine; - engine with system of cylinders deactivation (working cylinder);

-— · — · - engine with cylinders deactivation system (deactivated cylinder)

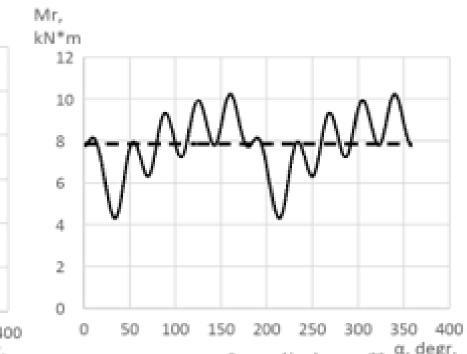


RESULTS OF DYNAMIC CALCULATION OF THE LOWER CRANKSHAFT

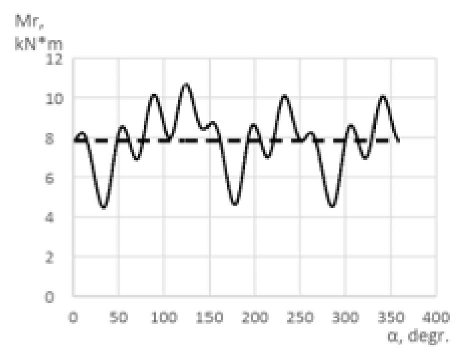
The **value of total torque** on the flange of the crankshaft of the base engine, and the engine with 1 to 6 cylinders deactivated at the same power mode (Ne = 200 kW)



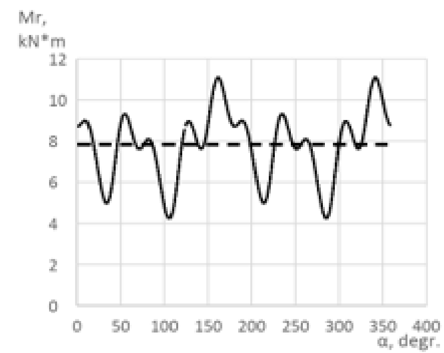
1 - cylinder off



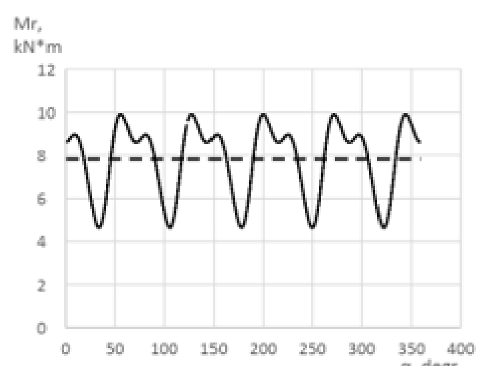
2 - cylinders off



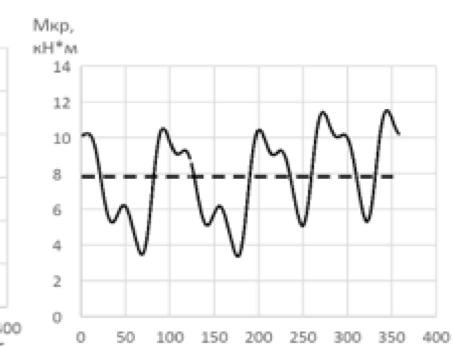
3 - cylinders off



4 - cylinders off



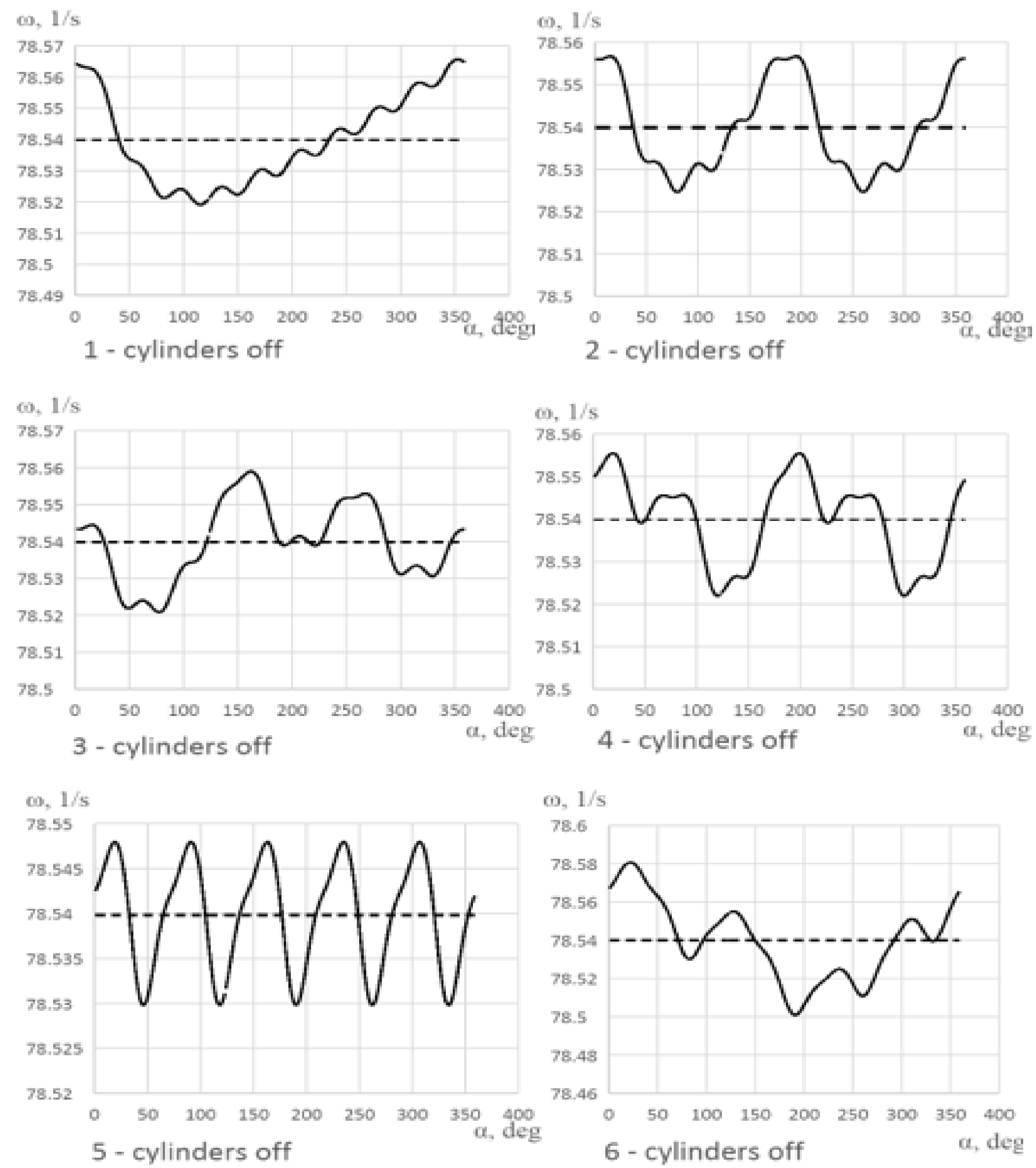
5 - cylinders off



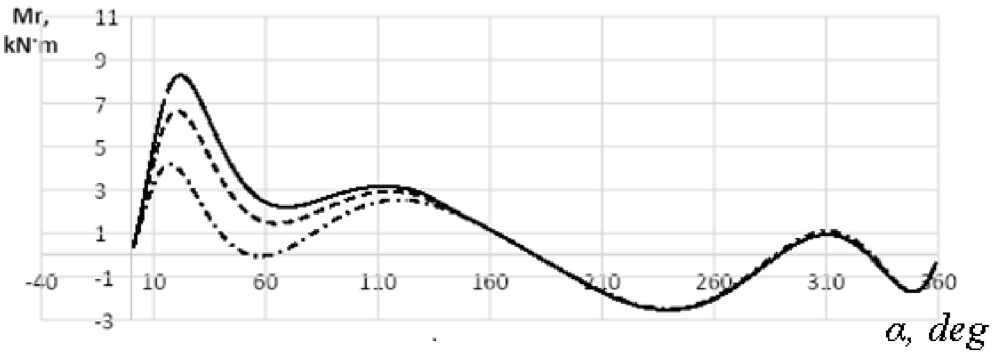
6 - cylinders off

RESULTS OF THE LOWER CRANKSHAFT DYNAMIC CALCULATION

The value of the **current angular velocity** of the crankshaft of the base engine, and the engine with 1 to 6 cylinders deactivated at the same power mode (Ne = 200 kW)

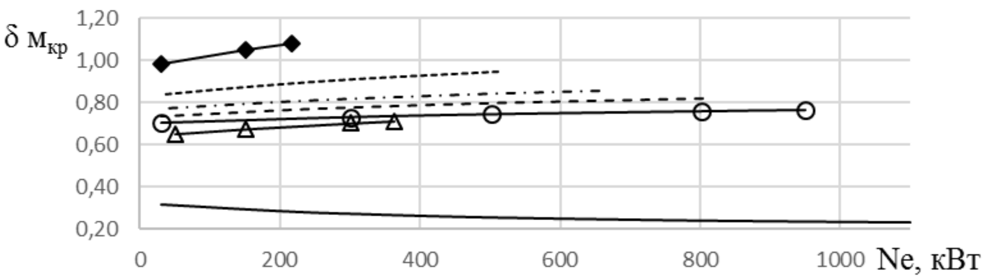


RESULTS OF THE LOWER CRANKSHAFT DYNAMIC CALCULATION



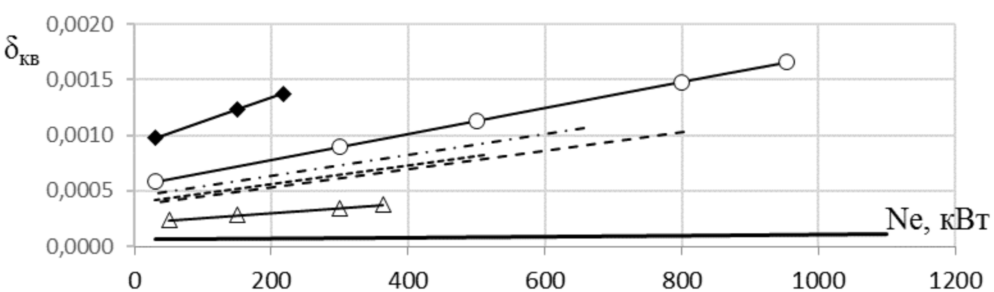
The value **of current and average torque** on the engine crank in the Ne = 200kW mode:

- - - base engine; - engine with system of cylinder deactivation (working cylinder); — · — · - engine with system of cylinder deactivation (deactivated cylinder)



Torque unevenness of the engine on modes of loading characteristics:

——— 10 cylinders; O—— 9 cylinders;
- - - 8 cylinders; —·— 7 cylinders;
········ 6 cylinders; Δ—Δ 5 cylinders;
◇—◇ 4 cylinders



Cyclic irregularity of the engine on modes of loading characteristic

CONCLUSIONS ON THE RESULTS OF THE LOW CRANK GEAR DYNAMIC CALCULATION OF THE ENGINE WITH CYLINDERS DEACTIVATION SYSTEM

1. When some of the cylinders are deactivated there is a significant increase in forces, torques on the cranks in the working cylinders

2. Cylinders deactivation leads to a significant increase in engine torque unevenness (up to 3.0 and 3.75 times).

3. When deactivating the cylinders, the crankshaft cyclic speed fluctuation increases significantly (up to 17 and 18 times). It should be noted that despite the significant increase in cyclic speed fluctuation when disconnecting the cylinders, this parameter does not exceed the permissible values for engines - AC generators($[\delta]=0,005$).

4. The most favorable from the point of view of the smallest increase in non-uniformity of torque and crankshaft speed fluctuation is five cylinders deactivation. When using other options for disconnecting the cylinders, the crankshaft speed fluctuation is much greater, but does not exceed the allowable values for current generators.

DEVELOPMENT OF A CYLINDER DEACTIVATION ALGORITHM IN A RANGE OF OPERATING MODES

Under the algorithm of cylinder deactivation, we understand the exact sequence of actions aimed at the exclusion of cylinders or groups of cylinders, depending on the complex of operating parameters of an engine.

As the main criterion for switching off the cylinders, the indicator efficiency ηi is selected. At each mode of the engine, the ηi is compared for the engine with different number of cylinders deactivated. Those number of cylinders are selected, at which the indicator efficiency is the largest. In definite power range when working on z cylinders (where the indicator efficiency is the largest) power of the engine changes in a qualitative way by changing the mixture composition.

DEVELOPMENT OF A CYLINDER DEACTIVATION ALGORITHM IN A RANGE OF OPERATING MODES

Limitations:

Maximum combustion pressure in the working cylinders, the excess of which leads to an increase in the stiffness of combustion and excess loads on the parts of crank gear. In the work, it is assumed that this pressure should not exceed the values achieved in the mode of nominal power of the engine and constitutes 8 MPa;

- It is the need to maintain the value of **cyclic irregularity** δ which shouldn't be more than 0.005;

- It is a significant **cooling of cylinders which are deactivated** during long-term operation at a certain load mode. This leads to an increased wearing of the cylinder, deterioration of lubricating conditions in friction pairs in the crank gear, the growth of mechanical losses. In order to reduce the negative effect the engine cylinder cooling, it is recommended that the cylinder shut-off order was floating along the cylinders firing order.

DEACTIVATING ALGORITHMS FOR ENGINE CYLINDERS ALGORITHM 1

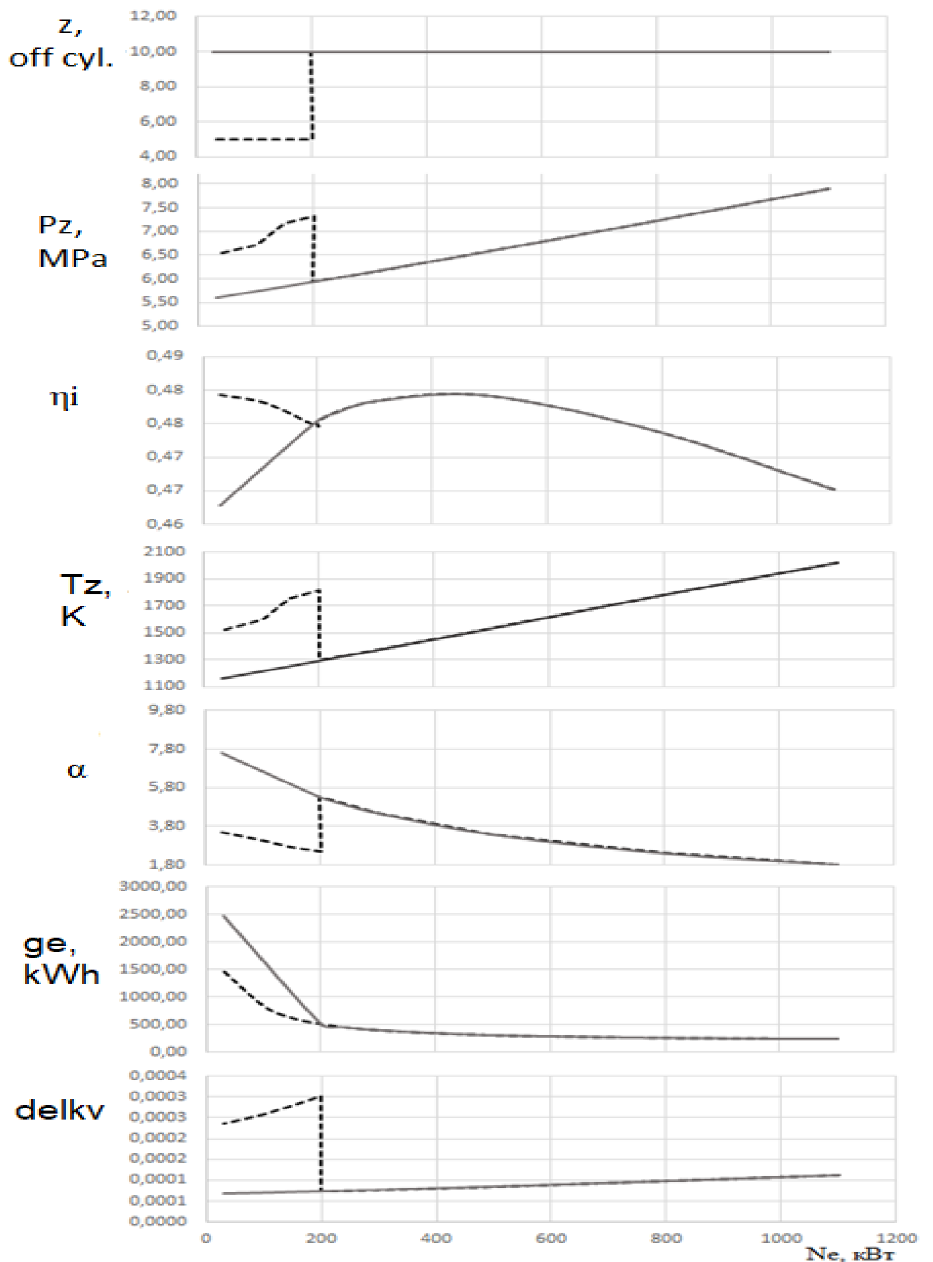
Power range	Number of cylinders deactivated	Number of working cylinders	The numbers of cylinders in the firing order									
			1	6	10	2	4	9	5	3	7	8
			The firing order									
			1	2	3	4	5	6	7	8	9	10
	Algorithm 1											
200-1100 kW	0	10	0	0	0	0	0	0	0	0	0	0
0-200 kW	5	5	1	0	1	0	1	0	1	0	1	0

Note: *0 - working cylinder; 1 – deactivated cylinder.

DEACTIVATING ALGORITHMS FOR ENGINE CYLINDERS ALGORITHM 1

Algorithm 1 is proposed to provide the low cyclic irregularity and, in the same time, high levels of the indicator efficiency. While turning off five cylinders, the cyclic irregularity is the lowest among the other variants of cylinders deactivating. In addition, this algorithm differs in the simplicity of implementation and design support.

- - - - base engine; — engine with system of deactivation cylinders by algorithm 1

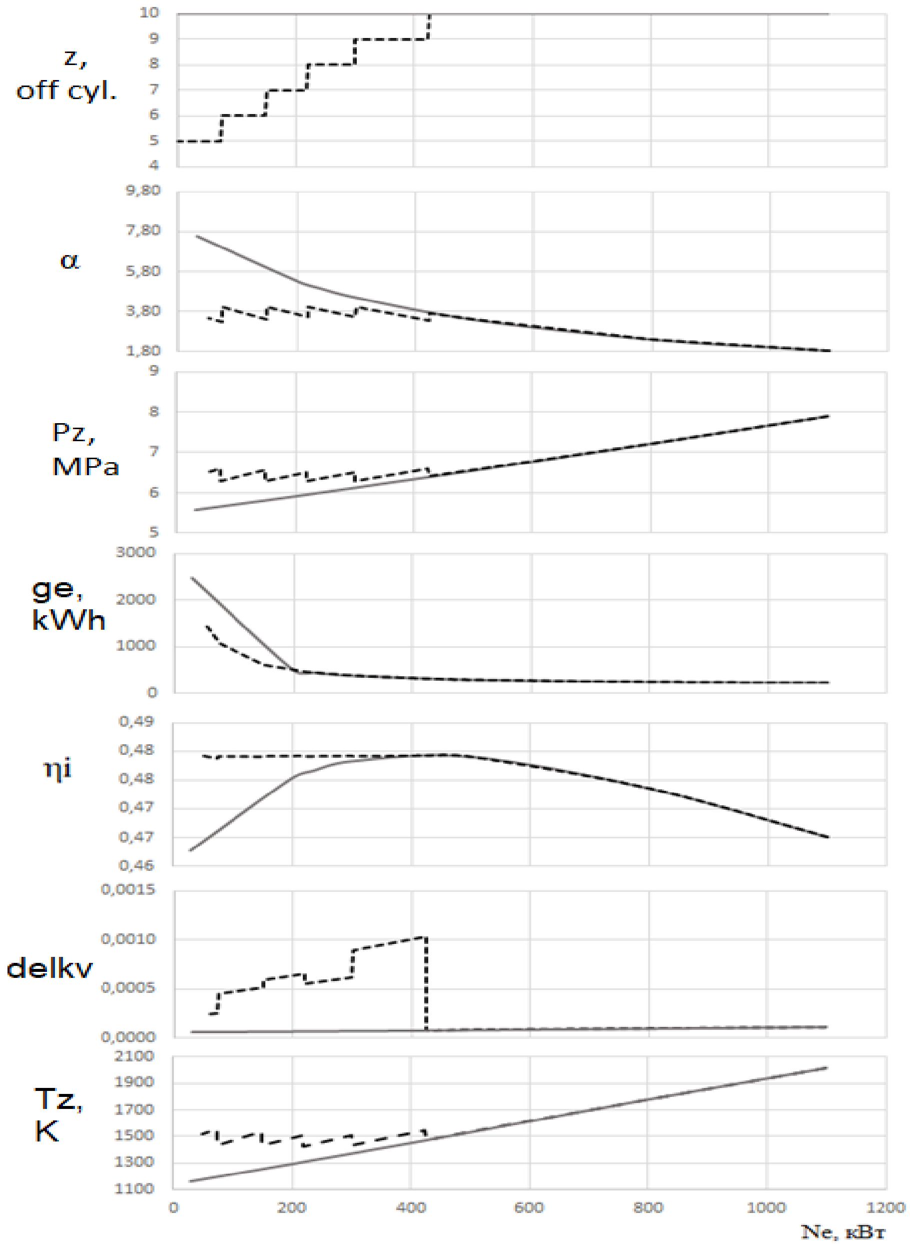


DEACTIVATING ALGORITHMS FOR ENGINE CYLINDERS
ALGORITHM 2

Power range	Number of cylinders deactivated	Number of working cylinders	The numbers of cylinders in the firing order									
			1	6	10	2	4	9	5	3	7	8
			The firing order									
			1	2	3	4	5	6	7	8	9	10
425-1100 kW	0	10	0	0	0	0	0	0	0	0	0	0
300-425 kW	1	9	1	0	0	0	0	0	0	0	0	0
220-300 kW	2	8	1	0	0	0	0	1	0	0	0	0
150-220 kW	3	7	1	0	0	0	1	0	0	1	0	0
73-150 kW	4	6	1	0	1	0	0	1	0	1	0	0
0-73 kW	5	5	1	0	1	0	1	0	1	0	1	0

Note: *0 - working cylinder; 1 – deactivated cylinder.

DEACTIVATING ALGORITHMS FOR ENGINE CYLINDERS ALGORITHM 1

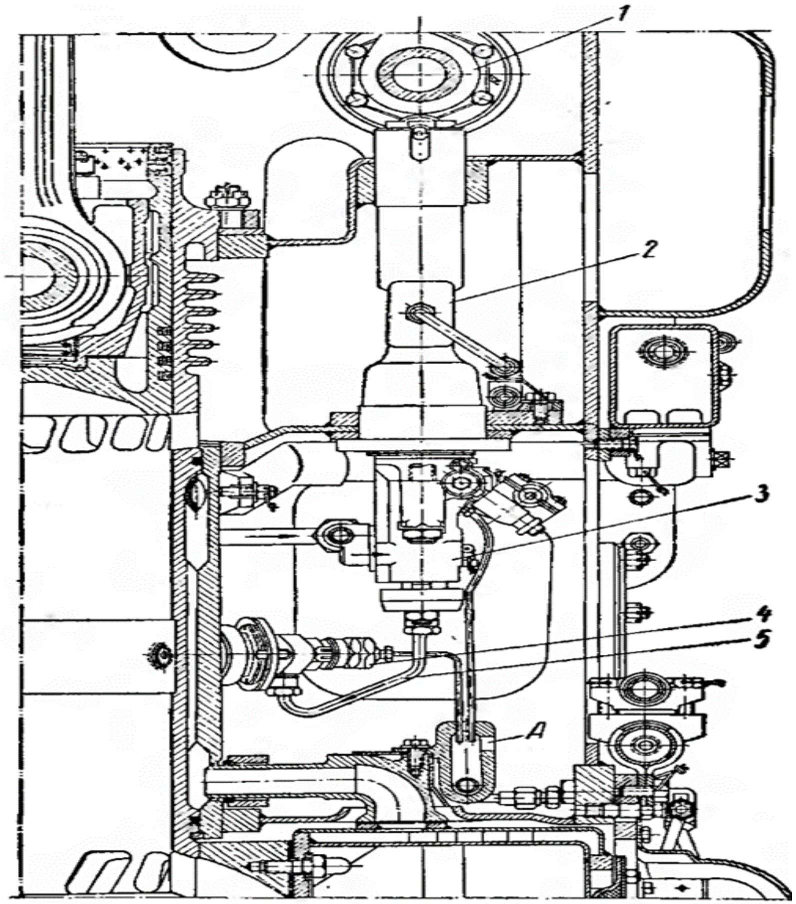


While implementing **algorithm 2**, the best values of the indicated efficiency and the best fuel-effectiveness are achieved. Though the crankshaft speed cyclic irregularity is higher than in case using the algorithm 1.

- - - base engine; — engine with the system of cylinders deactivation by algorithm 2

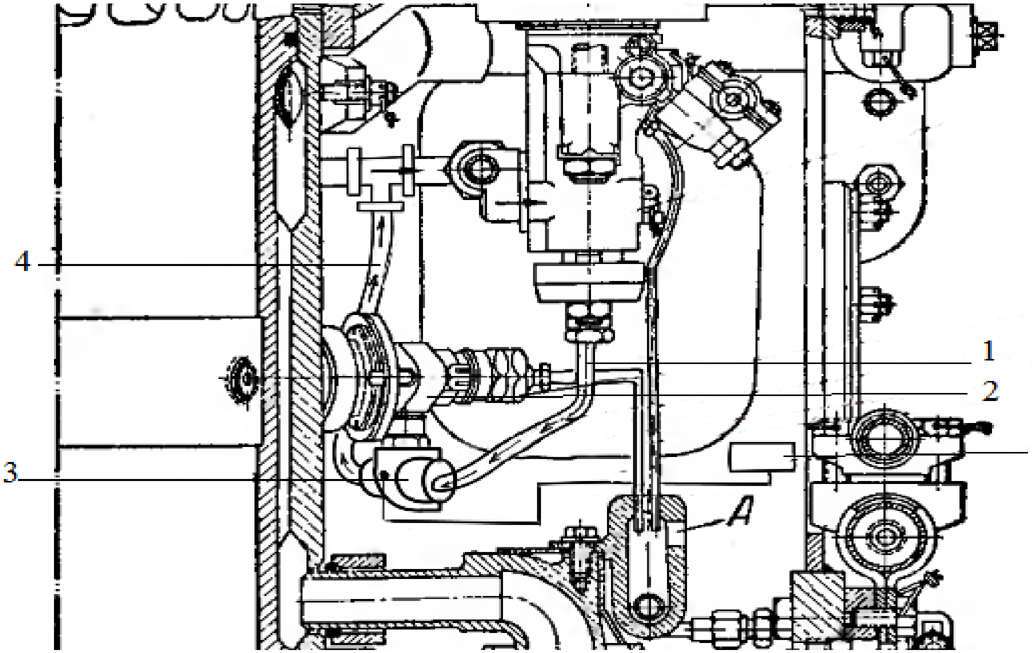
THE DESIGN OF CYLINDER DEACTIVATION SYSTEM

Internal (standart) fuel system



1 - camshaft; 2 - pusher; 3 - fuel pump; 4 - nozzle;
5 - a pipe of high pressure.

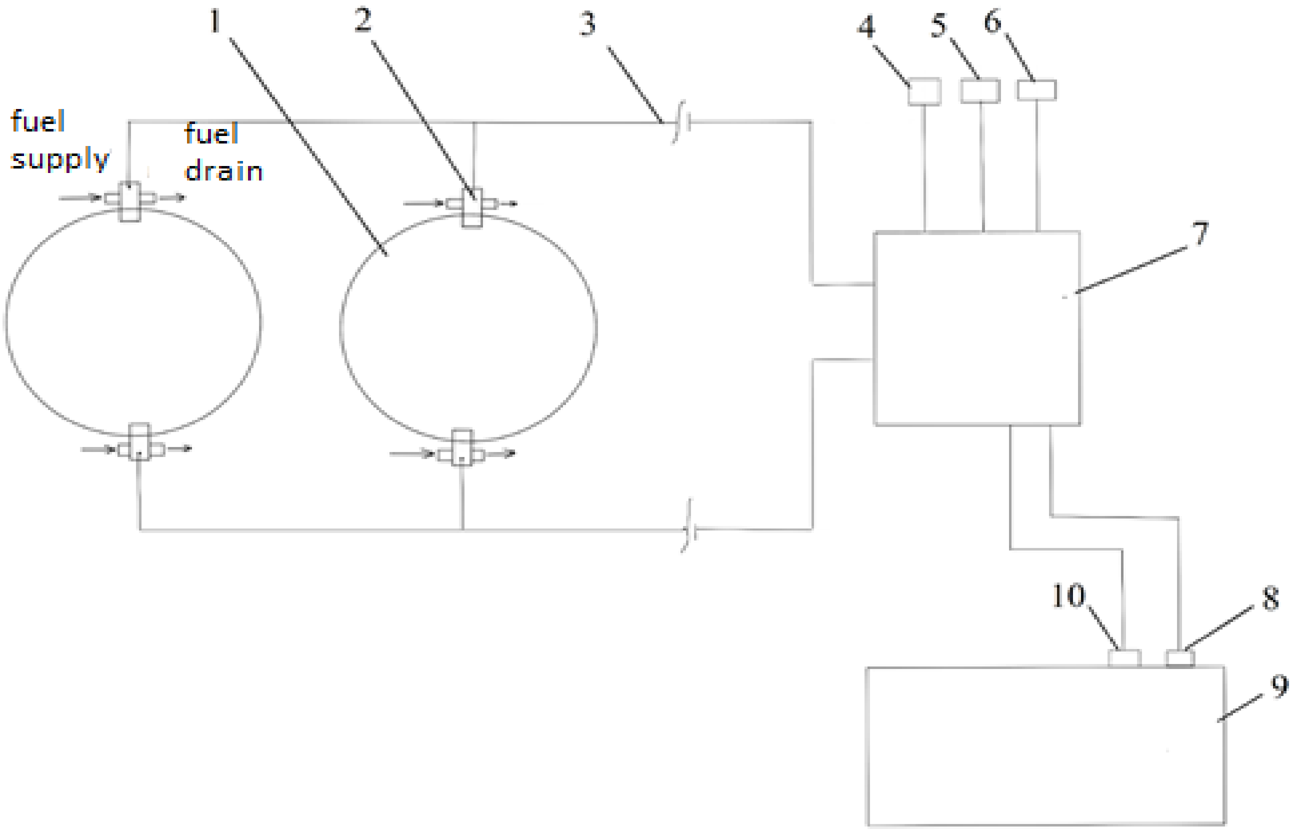
Modernized internal fuel system



1 - high pressure tube; 2 - nozzle; 3 - electromagnetic valve; 4 - fuel discharge pipe into low pressure system.

THE DESIGN OF CYLINDER DEACTIVATION SYSTEM

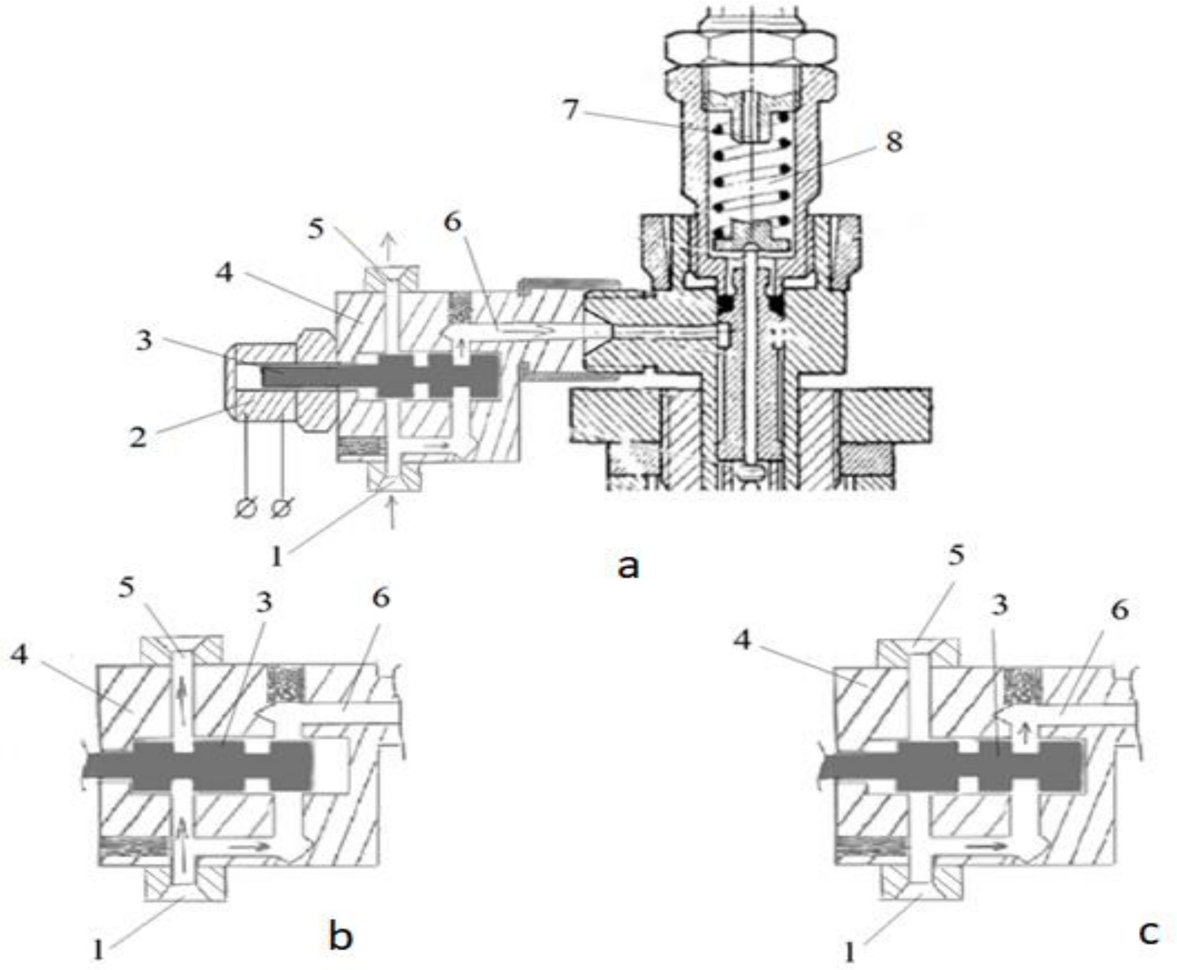
Cylinder deactivation system



1 - engine cylinder; 2 - nozzle with an electromagnetic valve; 3 - data transmission line; 4 - speed sensor; 5 - vibration sensor; 6 - coolant temperature sensor; 7 - electronic control unit; 8 - ammeter; 9 - voltmeter; 10 - generator.

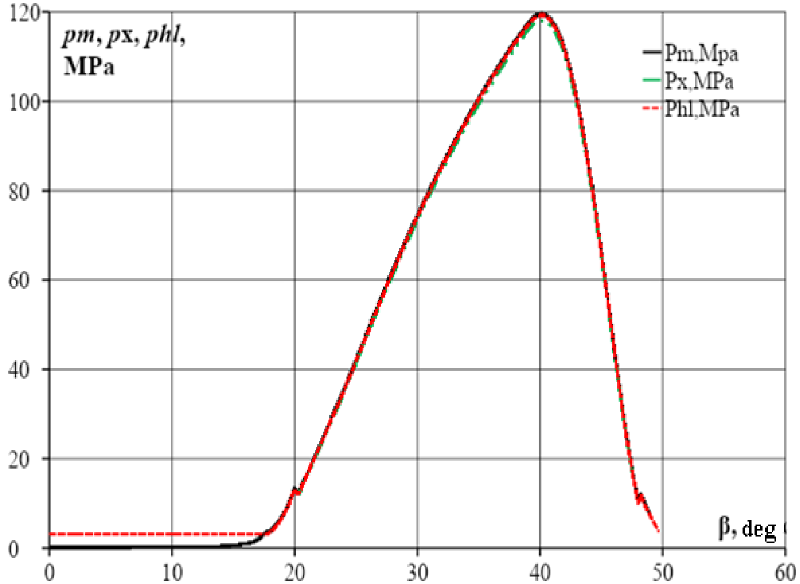
THE DESIGN OF CYLINDER DEACTIVATION SYSTEM

Electromagnetic valve for deactivating fuel supply

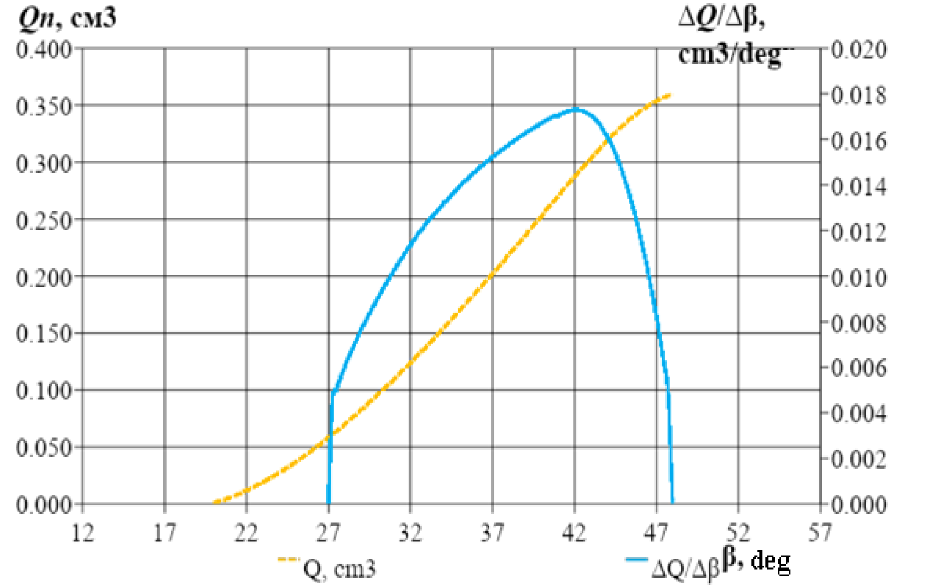


a-switch device; b – switching off the nozzle; c – turning on the nozzle; 1 - feed channel; 2 - electromagnet; 3 - spool; 4 - body; 5 - exit channel; 6-channel to nozzle; 7 - drainage channel; 8-volume of spring operation.

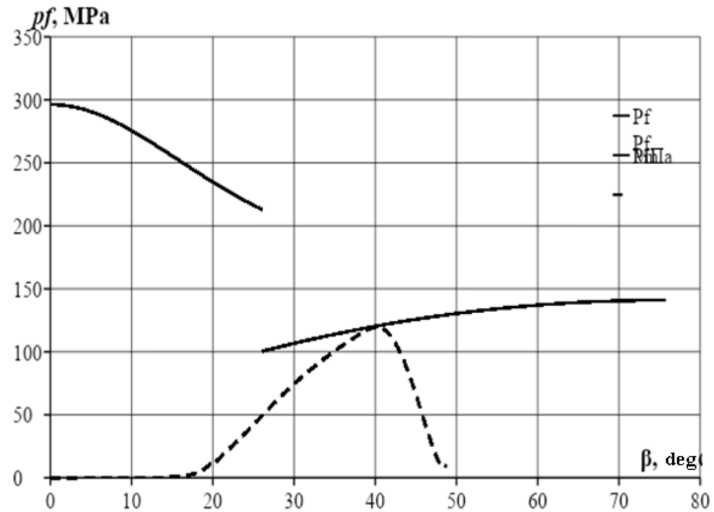
RESULTS OF FUEL SUPPLY CALCULATION



The main parameters of fuel supply



Differential and integral characteristics of fuel injection



Maximum allowable pressure and pressure in the over the plunger volume

PROJECT FEASIBILITY STUDY

Thesis costs

№	Name of the article of expenses	Amount, UAH
1	Cost of materials and semi-finished products	350
2	Transportation and procurement costs	42
3	Basic salary	108000
4	Extra pay	10800
5	Deductions for social events	26136
6	Amortization	6496
7	Total expenditures	35640
8	Production cost	37223
9	Administrative expenses	23760
1	Total cost	248447

ΔK – additional investment related to the development of new fuel equipment

$\Delta K = 248447 + 57970 = 306417\ UAH$

R_e - regulatory coefficient of efficiency, the value of the return on the payback period of additional capital ΔK, for the field of mechanical engineering R_e = 0,16.

Payback period

$$Pe_p = \frac{\Delta K}{E_E} = 306417/1020280{,}28 = 109 days.$$

Thus, based on the calculations and cost-effectiveness analysis, it can be seen that the production of a modified 7D100M engine is appropriate economically. From the calculations it follows, that the economic effect will be 1020280,28 UAH, and the payback period will be 109 days.

JOB AND ENVIRONMENT PROTECTION

The third-octave vibration level (dB) of the engine base above the shock absorber is approximately determined by the formula:

$$L_v = \left\{44 + 10lg\left[\frac{750 \cdot 1100^{0,55}\left(1 + \frac{1100}{29000}\right)}{1 + \left(\frac{12,5}{1500}\right)^3 \frac{29000}{1100}} + 30lg\left(\frac{750}{750}\right)\right]\right\} = 89,4\ dB$$

The vibration level does not exceed the permissible according to ДСН 3.3.6-039-99

To reduce the external noise created by the engine, a careful treatment of the crankshaft friction surface is made, high-quality wear-resistant bearings are used. An air purifier is an effective inlet silencer.

Thermal and catalytic converters built into the exhaust systems are used for the exhaust gas utilization; the toxicity can be reduced by 70 ... 90%.

Taking all these measures and means we can significantly reduce environmental pollution.

CIVIL PROTECTION

Civil protection is a function of the state aimed at protecting the population, territories, the environment and property from emergencies by preventing such situations, eliminating their consequences and providing assistance to victims in peacetime and during a special period.

The **main tasks** of the **Unified State System of Civil Protection**, namely:

1) ensuring the readiness of ministries and other central and local executive bodies, local self-government bodies, their subordinate forces and means to take actions aimed at preventing and responding to emergencies;

2) ensuring the implementation of measures to prevent emergencies;

3) training of the population on behaviour and actions in case of emergency;

4) implementation of state target programs aimed at preventing emergencies, ensuring the sustainable functioning of enterprises, institutions and organizations, reducing possible material losses;

5) processing of information on emergency situations, publication of information materials on the protection of the population and territories from the consequences of emergencies;

6) notification of the population about the threat and occurrence of emergencies, timely and reliable information about the actual situation and measures taken;

7) protection of the population in case of emergencies;

8) other tasks defined by law.

CONCLUSIONS

In the work the method of cylinder deactivation for a stationary diesel generator 7D100 was justified. The following problems are solved:

1 Load characteristics of the engine operating on different cylinders were calculated. It was shown that when the cylinders were deactivated at low load modes, the indicator and effective efficiency of the engine improved, the specific fuel consumption reduced. However, cylinder deactivation was the reason of maximum pressure increase in the combustion chamber, which led to the load on the crankcase details increase and reduction of their reliability.

2 Influence of the number of working cylinders on the forces and moments in the crank mechanism of the engine, the unevenness of torque and the crankshaft cyclic speed fluctuation was determined in the result of dynamic calculation. It was shown that cylinder deactivation leads to increase in the unevenness of torque and the crankshaft cyclic speed fluctuation. The greatest value of cyclic speed fluctuation was obtained when one and six cylinders were deactivated, the smallest one - when the five cylinders were deactivated. Despite the significant increase in the speed fluctuation when the cylinders were deactivated, this parameter did not exceed the permissible values for AC generators (0.005).

3 There were proposed the criterion by which cylinders are to be switched off (engine indicator efficiency), and limiting workflow parameters, which should not go beyond the specified limits (maximum combustion pressure, excess air ratio, uneven engine stroke).

4 Two algorithms for cylinders' deactivation were developed and the engine performance with the use of proposed algorithms was explored. The efficiency of this method of power regulation was proved.

5 The cylinder's deactivation system was developed; its operation features were considered.

6. The cam of the fuel pump is profiled and the calculation of fuel supply to the engine cylinder was performed/

7. Ehe economic feasibility of the work has been completed, issues of environmental protection, safety equipment and civil protection have been considered.