The Method of Increasing the Power Indicators of Engines of Gas-Cylinder Vehicles in Mountainous and Foothill Conditions

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Abstract: This article describes the method of automatic power compensation systems to increase the efficiency of use of the engines of ZIL and Gazelle trucks converted for operation on LNG and operated in the foothill and mountainous conditions. It was established that with additional air supply, the engine's power and torque increase by 11-14% for every 1000m of height increase above sea level as compared with a serial engine, but at the same time the specific consumption of gaseous fuel increases by 6 ... 8%.

Keywords: ZIL and Gazelle trucks, foothill and mountain conditions, pressure, temperature, humidity and crankshaft speed sensors.

Introduction

In Uzbekistan, about one million vehicles have been converted to liquefied and compressed gas. In the design and construction of traditional engines, the possibilities of their effective use in mountainous and foothill areas are rarely taken into account.

To improve the efficiency of using engines of ZIL and Gazelle trucks, converted to work on LNG and operating in foothill and mountain conditions, it is necessary to use automatic power compensation systems.

The research carried out have proven the promising nature of the use of gas injection systems. This provides:

- increase in engine power by increasing the filling factor, uniformity of the distribution of the combustible mixture over the cylinders;
- reduction of operating fuel consumption due to the precision of metering of injected fuel;
- compliance with modern environmental requirements;
- improving the dynamic qualities of the engine (car);
- achieving reliable engine start and quick warm-up;
- the possibility of forcing the engine according to the crankshaft speed.

Depending on the method of power supply of engines, GBA are subdivided into universal gas-petrol, gas-diesel and gas.

In modern foreign cars in the power supply systems, gas injection systems (4th generation) are used. This allows for power conservation while converting the base engine to run on CNG. However, this system allows gas engine power to be retained only in flat conditions.

From the beginning of the 70s to the present, the operated GBVs are equipped mainly with gas equipment from various manufacturers of the Russian Federation, Belarus, and Ukraine. In recent years, the Uzbek market began to replenish with HBO of foreign firms (Italy, South Korea, Turkey, Germany, etc.) for cars and light vehicles [6].

The Main Findings and Results

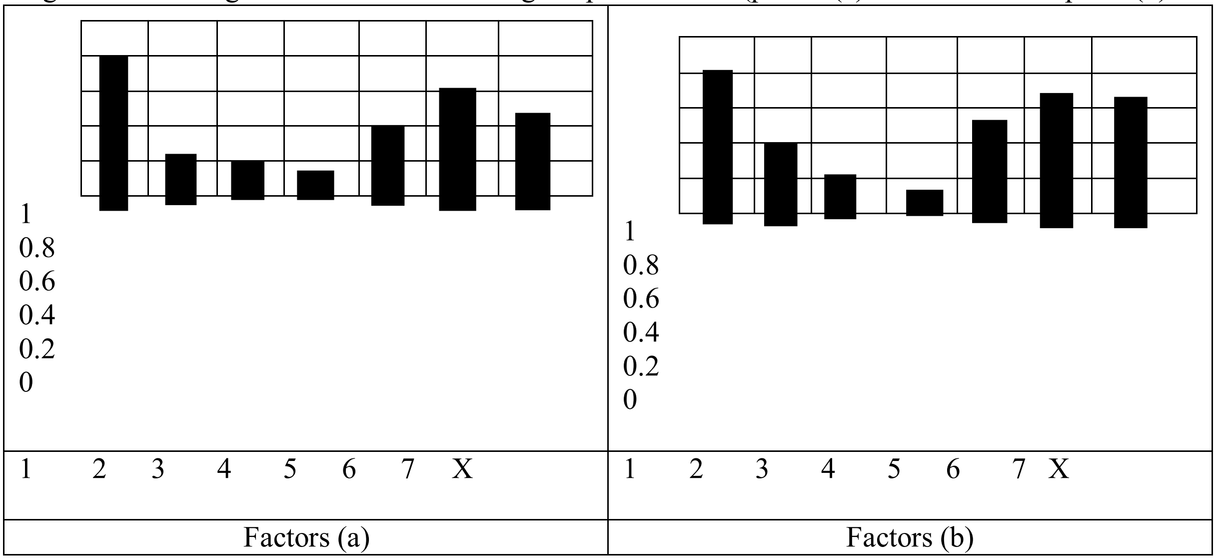
The advantage of universal LPG or LNG-fueled NGVs is that after the gas is consumed, you can quickly switch to full engine operation on gasoline. In the context of an underdeveloped gas filling network, this is very important.

When the vehicle is running on LPG and CNG, the toxicity of exhaust gases decreases: CH by 1.1-1.4 times, CO by 2-4 times, NOx by 1.2-2.0 times.

The gas cylinder is under high overpressure and this requires compliance with more stringent measures for the safe operation of the GBA.

In fig. 1. The weight of the factors influencing the indicators (power (a) and fuel consumption (b) of GBA engines in the foothill and mountain conditions is presented.

Figure: 1. the weight of the factors affecting the performance (power (a) and fuel consumption (b)



of GBA engines in the foothill and mountain conditions:

X_1 – barometric pressure OC; X_2 – temperature OC;
X_3 – humidity OC; X_4 - technical condition of the engine;
X_5 - supply system; X_6 - road conditions; X_7 – fuel property

The analysis shows that the power and economic indicators in mountainous conditions are most influenced by the OS pressure (X_1), the power system (X_5), road conditions (X_6) and fuel properties (X_7).

High altitude conditions make independent requirements for internal combustion engines:

1. The area of predominantly used operating modes of the engine (trucks) in mountainous conditions expands by about 25-30% and is shifted towards the external characteristics by 30-40%.
2. When operating in foothill and mountainous terrain, the speed of the engine becomes significantly heavier. If under normal conditions the engine mainly operates in the range of 900-1700 min^{-1}, then in mountainous conditions the speed zone is expanded to 2800 min^{-1}.
3. The duration of the engine operation in the forced idle mode, when the engine is used as an absorber of the kinetic energy of the driving car, is 17-26%.

With an increase in altitude for every 500 m, the main indicators of the traction qualities of the GBA on average change as follows:

1. The dynamic factor is reduced by 8%.
2. The maximum speed is reduced by 3%.
3. Vehicle acceleration is reduced by 10%.

The profile of a mountain road makes it necessary to often use lower gears, since they have to be used not only on uphills, but also on steep descents in order to increase the safety of the vehicle. The study of the duration of using the gears of the ZIL-431410 car during its operation on mountain and foothill roads showed that in the first gear the car moves for 11.4% of the time, in the second gear - 32.4%, in the third gear - 20.2%, in IV gear - 34.1%, and in V gear - 1.7% of the time.

Numerous observations [24, 54] have established that the average speed on mountain roads is 40-60% lower than on flat roads, and fuel consumption on mountain roads increases by 10-15%. When driving in mountainous and foothill conditions at a speed of 60 km / h, LNG consumption by the ZIL-431410 vehicle is 36.2 m3 / 100 km (31.2 kg / 100 km). That’s 18% more than LNG consumption under normal conditions.

Table 1

Operational modes of GBA in mountain conditions (for example, Kamchik pass)

Working conditions	Height, m				
	Plain	Foothill	Mountain		
	±200	300-700	0-1000	0-2000	0-3000
Engine running time under load. %	79	68	52	69	72
Duration of engine operation in non-traction mode (braking mode),%	-	9	31	21	24
Rest (no load, idle)	21	23	17	10	4

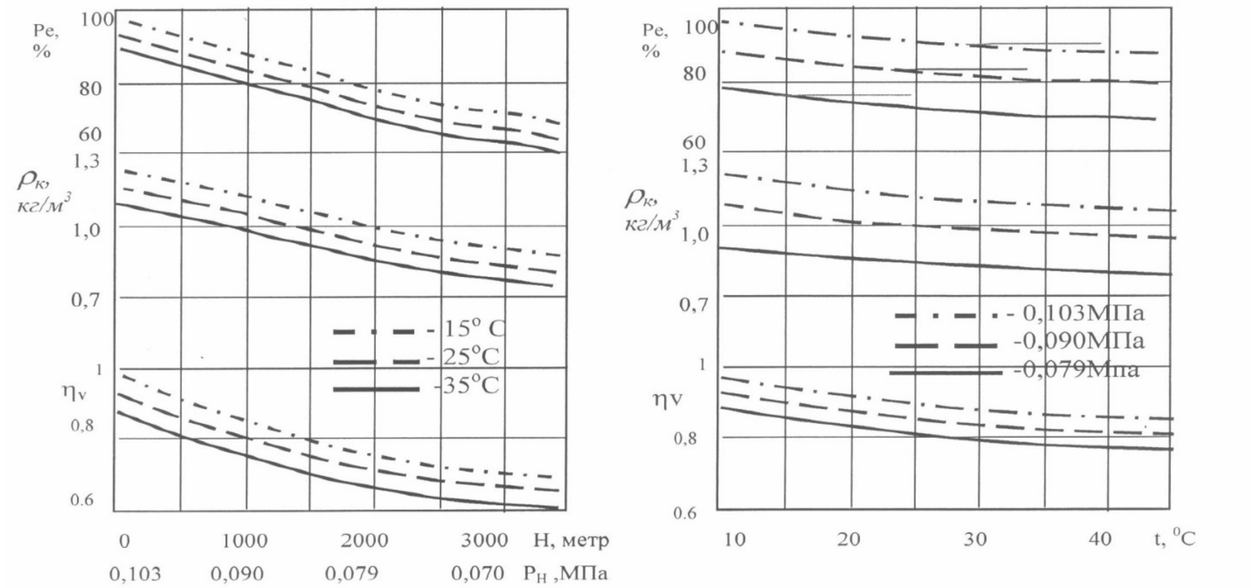


Figure: 1. Change in charge density, average effective pressure and engine filling ratio depending on temperature and pressure

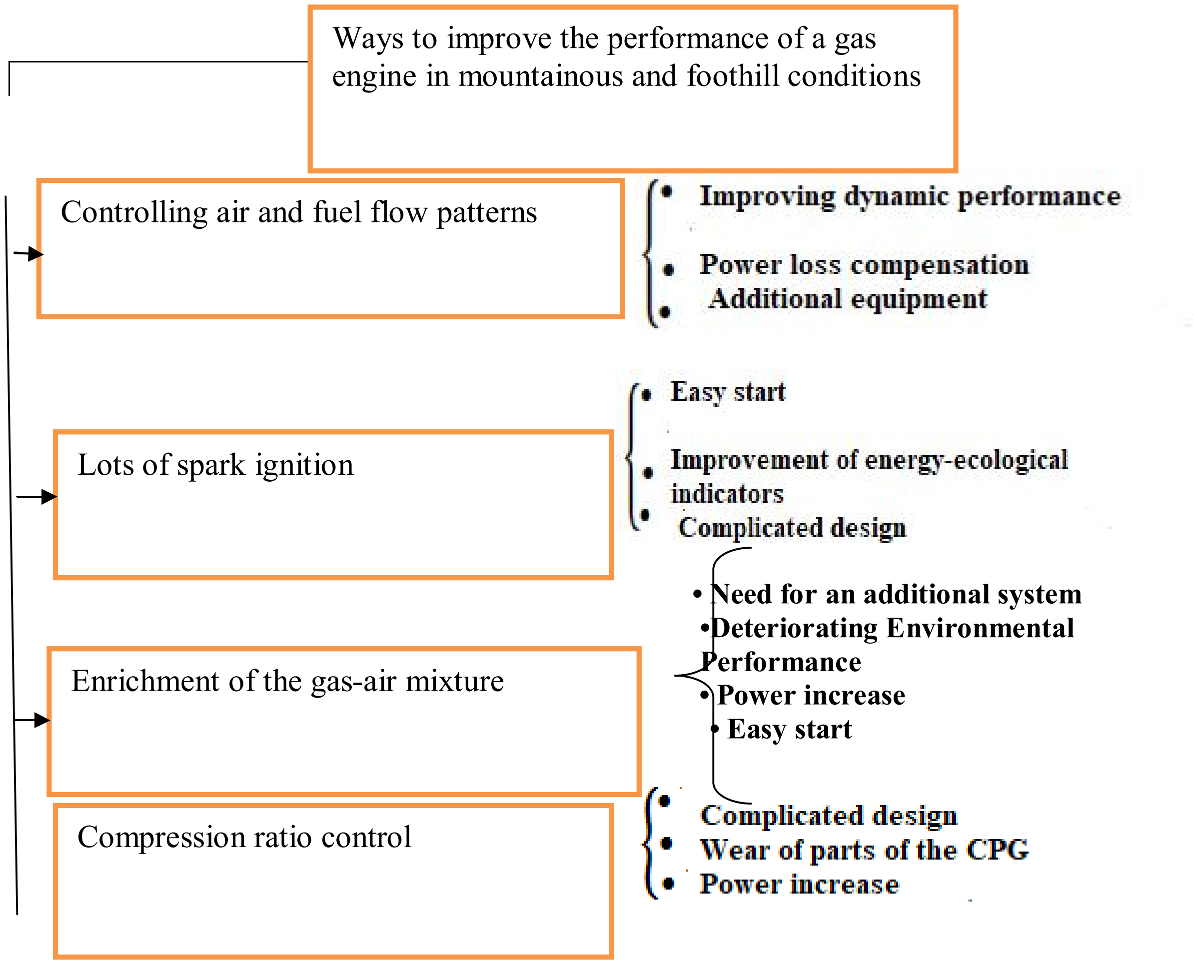


Figure: 2. Scheme of methods and means for improving the performance of internal combustion engines
on gaseous fuels in mountainous and foothill conditions

In fig. 3 shows a diagram of the automatic altitude compensation for the power loss of an LNG engine.

When using automatic systems for compensating for power loss in high-altitude conditions, the control elements are mainly pressure, temperature, humidity and crankshaft speed sensors.

Table 2

№	Indicators	Engine brands	
		ZIL-431410	ZMZ-4026.10
1	Cylinder diameter, mm	95	92
2	Piston stroke. mm	100	92
3	Engine displacement, l	5.66	2.445
4	Compression ratio	7.1	8.2
5	Number of cylinders	8	4
6	Gasoline fuel system	Ejector	Ejector
7	Gas fuel system	Vacuum unloading	Vacuum unloading
8	Maximum torque moment on gasoline. Nm	382 at n = 1800min^{-1}	178 at n = 1700min $^{-1}$
9	Maximum capacity for LNG (plain), Nm	92 при n=3200мин$^{-1}$	56 at n = 5400min^{-1}
10	Maximum torque on LNG (plain), Nm	338 at n = 1800min $^{-1}$	156 at n = 1700min^{1}

Table 3

Advantages and disadvantages of using gas fuels in an internal combustion engine compared to gasoline engines

Advantage	disadvantages
Feasibility study	
The service life of engine oil increases 1.5-2 times	Requires a large space for the installation of cylinders, reducing the carrying capacity
Engine service life is increased by 1.5 times	Due to the installation of cylinders, the weight of the car increases by 10-15%
Spark plug life increased by 40%	If the setting is incorrect, untimely maintenance may occur выгорание клапанов
If the power system is damaged, gas does not enter the engine compartment	
No gas entering the engine cooling system	Engine operation at higher temperature conditions
Normal start at subzero temperatures (-5 ° C)	Reduces engine power by 12-20%, torque by 15-18%
The noise level of the engine operation is reduced by 7-8 dBA	Slower flame spread
Environmental assessment	
CO emissions are 20-25% less than when using gasoline. The exhaust fumes of natural gas vehicles are cleaner than those of ICEs fueled by diesel or gasoline	The desire to reduce the concentration of CO and CH by bringing the working mixture closer to stoichiometric for converted engines leads to an increase in the concentration of NOx emissions. Working on lean mixtures reduces the aggregate power, increases the CH emission, requires very flexible mixed (quantitative and qualitative) control

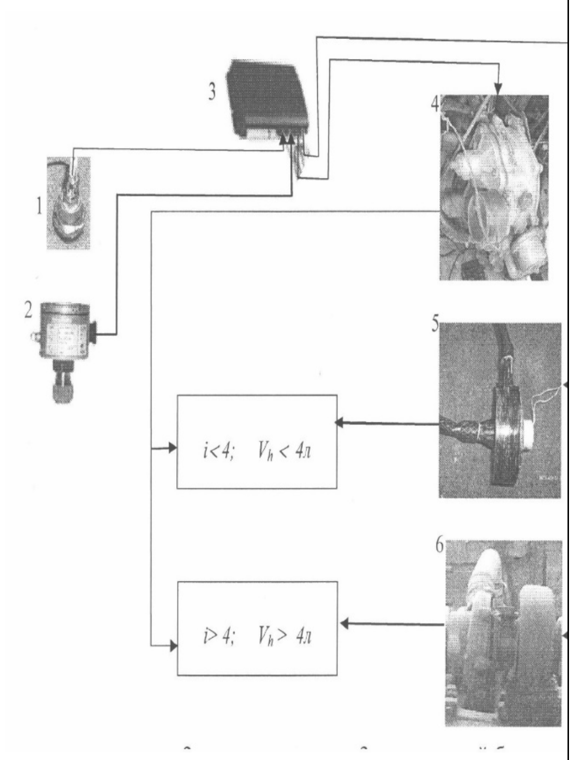


Figure: 3. Scheme of automatic altitude compensation for the power loss of an LNG engine:
1 - temperature sensor; 2 - pressure sensor; 3 - electronic control unit;
4 - gas reducer with an additional valve; 5 - controlled supercharger;
6 - turbocharger with a control valve

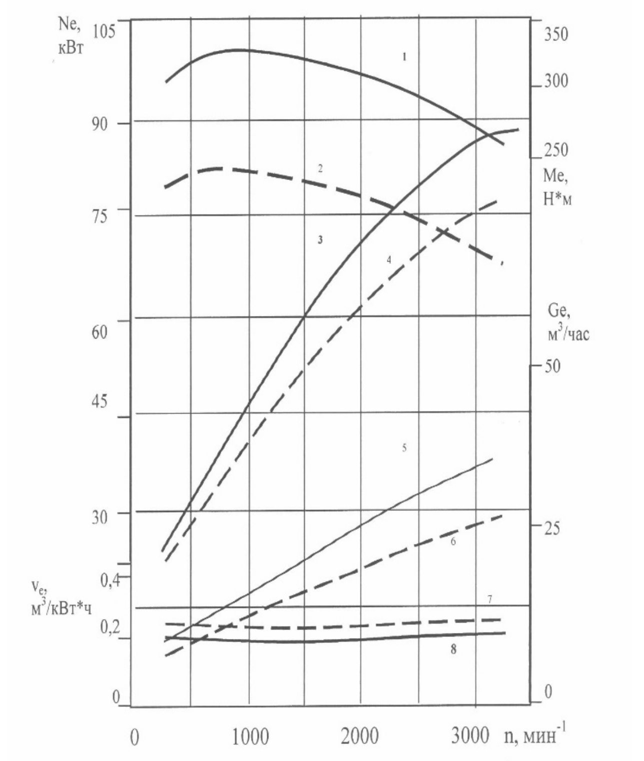


Figure: 4. Calculated assessment of the effect of altitude above sea level on the speed characteristic of the ZIL-431410 gas engine with and without power compensation measures:
1-motor torque with compensation; 2-motor torque without compensation; 3-motor power with compensation; 4-engine power without compensation; 5-hour engine fuel consumption with compensation; 6-hour engine fuel consumption without compensation;
7-specific engine fuel consumption without compensation; 8-specific fuel consumption of the engine with compensation

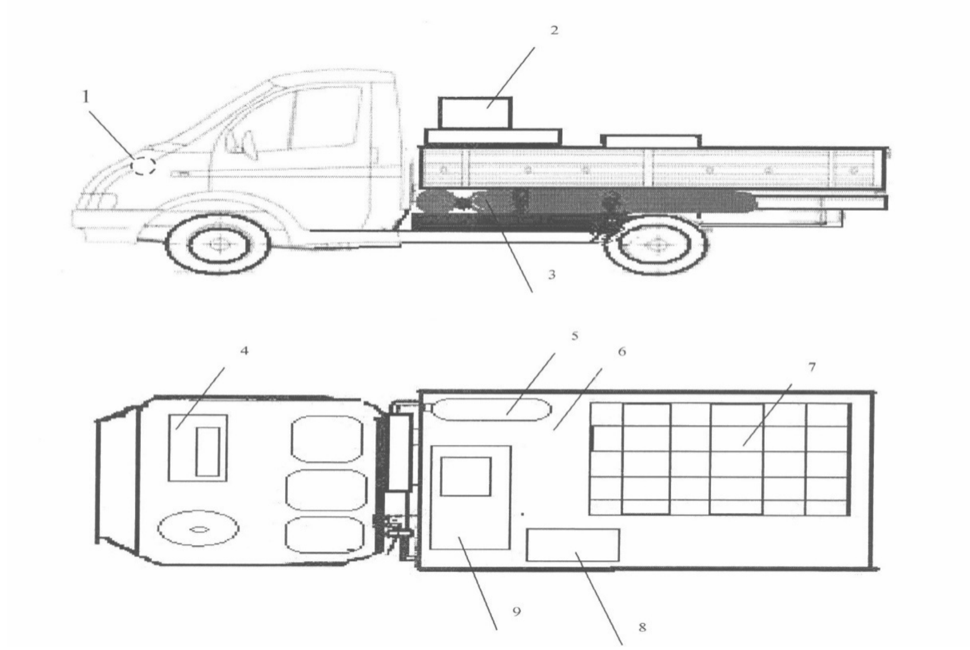
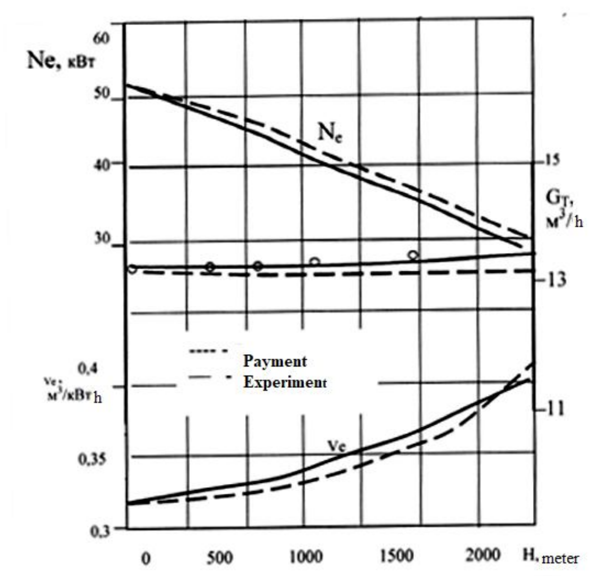


Fig: 5. Mobile laboratory for researching the working process of gas engines:
1-air flow meter, 2-oscilloscope, 3-gas cylinders,
4-control panel, 5-additional cylinder for measuring gas consumption,
6- platform, 7-load, 8-power station, 9-table

In fig. Figures 6 and 7 show the altitude (partial) speed characteristics of the engines of gas-cylinder vehicles ZIL-431410 and ZMZ-4026.10.



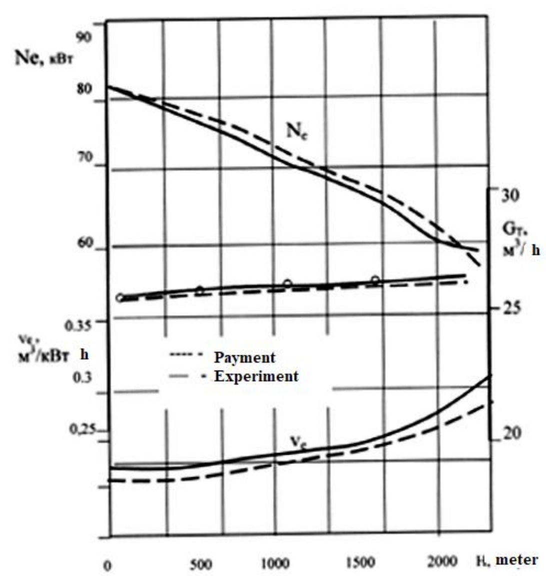
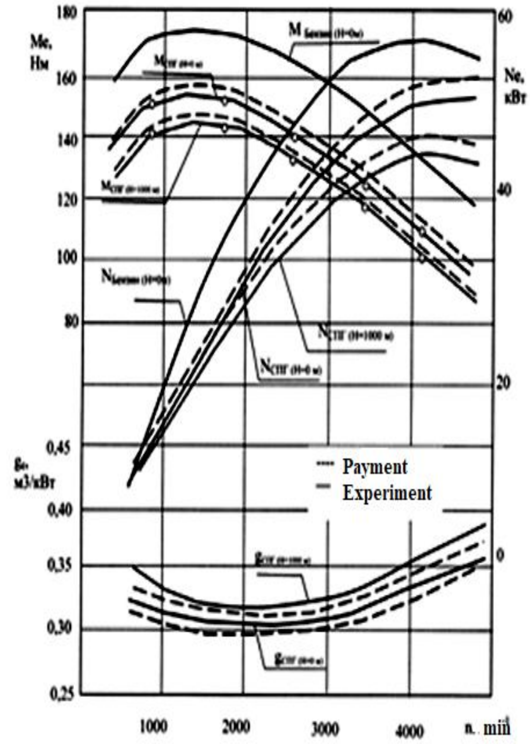


Fig. 6. Influence of the terrain altitude above sea level on the performance of the gas engine (ZMZ-4026.10) (n = 3600 min-^{1})

Fig. 7. Influence of the terrain altitude above sea level on the parameters of the ZIL-431410 gas engine (n = 2600 min-^{1})



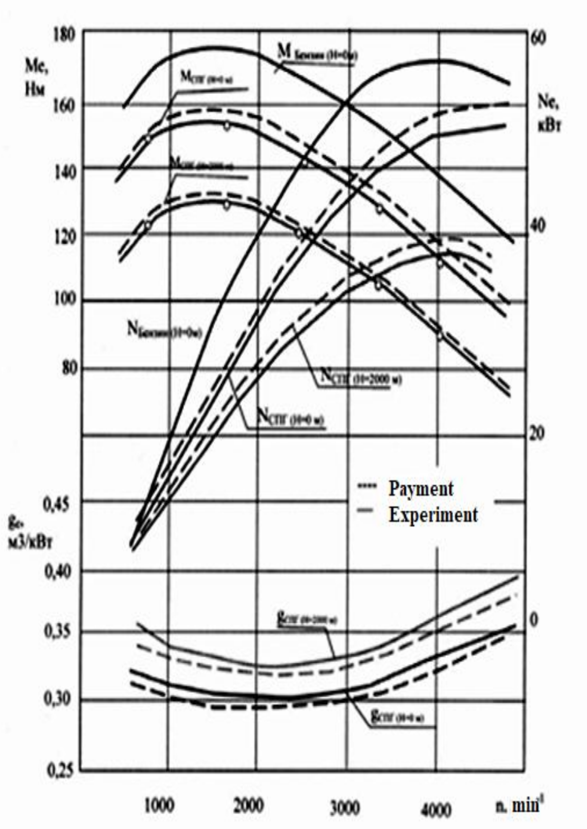


Fig: 8. Comparison of speed characteristics of engines (ZMZ-4026.10) operating on different fuels in high-altitude conditions (0-1000 meters above sea level)

Fig: 9. Comparison of speed characteristics of engines (ZMZ-4026.10). Working on various fuels in high-altitude conditions (0-2000 meters above sea level)

Figures 8 and 9 show the speed and altitude characteristics of the ZMZ-4026.10 engine with additional air supply, taking into account the height above sea level.

It was found that with additional air supply, the engine power and torque increase by 11-14%, but the specific consumption of gas fuel increases by 6 ... 8% for every 1000m of altitude increase in comparison with the serial engine.

The operating experience and the results of testing the ZMZ-4026.10 gas engine in high-altitude conditions showed that for the complete combustion of 1 kg (m3) of fuel, the excess air ratio should be within $\alpha \geq 1{,}1$.

Table 5

Change in the hourly air consumption of the serial engine ZMZ-4026.10 depending on the altitude at different gears of the checkpoint (n = 3200 min-^{1})

Gearbox transmission	Hourly air consumption, G_w m^3 / hour			
	1200м	1600м	1800м	2100м
II	144	133	121	112
III	138	123	116	109

Table 6

The required amount of additional air to fulfill the condition α = 1.15, taking into account the altitude at different gears of the checkpoint (n = 3200 min-[1])

Gearbox transmission	Required amount of additional air							
	1200м		1600м		1800м		2100м	
	kg/ h	м^3/h	kg/h	м^3/h	kg/h	м^3/h	kg/h	м^3/h
II	13.9	12	18.4	18	22.1	23	28.4	31
III	21	18	27.8	27	37.4	39	44.9	49

For the GBA ZIL engine, a TKR-6 turbocharger with an automatically controlled exhaust gas bypass valve was chosen to supply additional air. The fuel supply was controlled according to the above method.

Experiments with additional air supply show that this method for gas engines is an effective way to maintain engine performance at the required level.

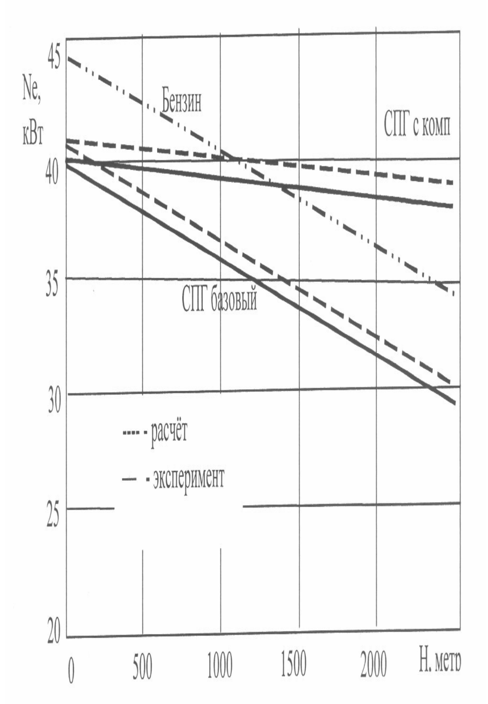


Fig. 10. Dependences of the change in the power of the ZMZ-4026.10 gas engine (at n = 2600 min-[1] with compensation (additional air supply) and without it

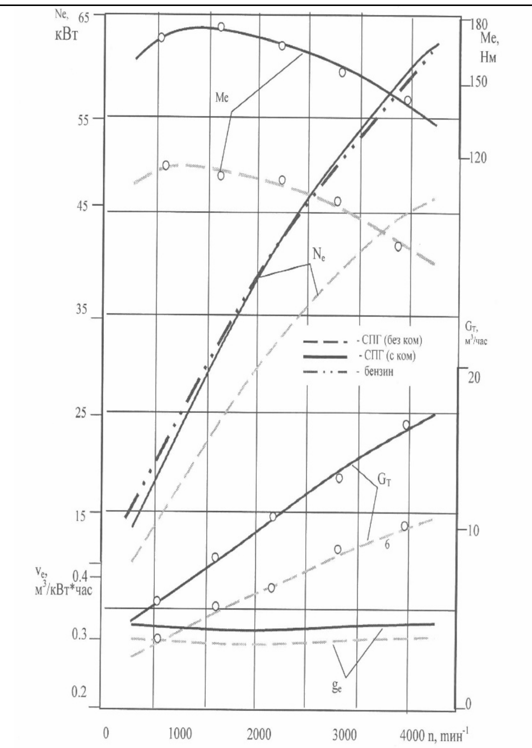


Fig.11. Influence of altitude above sea level on the speed characteristic of a gas engine (ZMZ-4026.10) with the use of (------) power compensation measures and without (- - - -) it (H = 2000 m)

Currently, the existing formulas for bringing gasoline engines and diesel engines to standard conditions take into account the influence of pressure, temperature and humidity, as well as the properties of the fuel. These include the formulas recommended by GOST 14846-81. For spark ignition engines, the reduction formula is:

$$N_{eo} = N_{eH} \cdot \left(\left(\frac{P_o - P_{o\,вп}}{P_H - P_{вл}} \right)^{1,2} \cdot \left(\frac{T_H}{T_o} \right)^{1,3} \right), ,$$

Where p_o, T_o - pressure and temperature of atmospheric air at standard atmospheric conditions;

$p_н$, $T_н$ - pressure and temperature of atmospheric air at high-altitude conditions;

r_{ov} - accepted standard water vapor pressure.

But it must be said that GOST 14846-81 mainly deals with the reduction factors for engines operating on liquid petroleum fuels.

Having solved these systems of equations, for gas engines we obtain dependencies for estimating the reduction coefficients K_{Ne} and K_{ge}:

$$K_{Ne} = \left(\frac{P - \varphi P_{ц}}{P_o}\right)^{\alpha} \cdot \left(\frac{T_o}{T}\right)^{\beta}; \quad K_{ge} = \left(\frac{P_o}{P - \varphi P_{ц}}\right)^{\alpha} \cdot \left(\frac{T}{T_o}\right)^{\beta}.$$

Where $\alpha = 0{,}56$ and $\beta = 1{,}74$ and 1.56 for CNG base engines,

$\alpha = 0{,}36$ and $\beta = 1{,}12$ and 1,24 for gas engines with compensation.

Table 7

Value K_{Ne} and K_{ge} for LPG vehicles running on compressed natural gas

Height above sea level (H), m	Base		Using automatic compensation systems	
	K_{Ne}	K_{ge}	K_{Ne}	K_{ge}
0	1	1	1	1
500	1,056	0,973	1,006	0,950
1000	1,143	0,969	1,031	0,927
1500	1,237	0,922	1,044	0,915
2000	1,337	0,903	1,065	0,859
2500	1,427	0,897	1,079	0,831
3000	1,467	0,857	1,101	0,798

An analysis of the table shows that when an automatic power loss compensation system is used in gas engines, it improves their power performance in comparison with the base engine by about 12%, but the specific fuel consumption increases by about 8%.

Conclusions

1. It has been established that for modern GBAs with an increase in altitude (from 0 ... 2500 meters), due to a decrease in air density, on average, it is possible to take a decrease in the effective engine power by 13-15%, an increase in specific fuel consumption by 10-11% per 1000 m. improving the performance of the GBA, it is necessary to improve the working process of the gas engine by using automatic power loss compensation systems.

2. The use of automatic control systems for additional air supply and mixture regulation at various altitudes above sea level allows an average effective power of the gas engine to be increased by 11-14% for every 1000 m of rise. However, at the same time, due to additional fuel supply at $\alpha = const$, the specific fuel consumption increases by 7% for every 1000 m of altitude.

3. The developed model of automatic power loss compensation and the machine calculation algorithm allows performing engineering calculations and determining the effect of the use of automatic power loss compensation systems on the internal combustion engine indicators, and the derived formulas for determining the required boost pressure and gas consumption, as well as formulas for bringing effective indicators to standard conditions, are in good agreement with experimental data.

4. Road-operational tests of GBA engines (ZIL-431410 and ZMZ-4026.10) have experimentally proved that the automatic power loss compensation system allows keeping their performance at the standard level.

5. Taking into account the altitude, equipping GBA engines operating in the Republic of Uzbekistan with automatic power loss compensation systems will provide significant economic benefits due to savings in liquid petroleum fuels and increased vehicle capacity.

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