Influence of electromagnetic atomizers’ technical condition on power and ecological indicators of gasoline I.C.E. in operation

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Abstract. Productivity of electromagnetic atomizers (EMA) of gasoline engines has been defined. It is established that EMA productivity removed from engine with an operating time of 30-60 thousand km, as well as new atomizers after their washing by ultrasound can change both productivity growth, and its decrease. It is shown that the content of PCO and \( \text{C}_\text{H} \) in the exhaust gases of car GAZ-27040 V (run of 30 thousand km) at engine work (on idling turns) with washed MA is below concentration of the specified toxic components in exhaust gases of the motor completed by unwashed ultrasound EMA. It is established that the difference in compared values of capacity and a torque, obtained in testing on dynamometric stand (subroutine \( P_{\text{max}} \), for the EMA engine before processing by ultrasound) is not significant. In the tests conducted in subroutine \( V_{\text{const}} \), the gain of capacity of the EMA engine washed out by ultrasound has been 0.04 MJ·km\(^{-1}\) (1.71%).

Keywords: electromagnetic atomizers, gasoline engines, capacity, torque.

1. Introduction

It is known that the technical condition (TC) of electromagnetic atomizers (EMA) influences the work of the gasoline engine [1-9]. The reasons of TC disturbance of fuel injection device are unstable work of the engine (jerks and failures at loading increase on the power unit), its capacity decrease, the fuel consumption increase, the raised toxicity of the exhaust gases [1-3]. Therefore, timely disturbance diagnostics of working EMA, restoration of its working capacity are the problems which decision is really actual nowadays.

Being a device of fuel injection, EMA’s main failures are solenoid coil-winding circuit, decrease of needle valve spring rigidity, needle hanging-up of the valve in extreme top or bottom positions [9]. The reasons influencing atomizer working capacity, can be (as a result of thermal influence) surface deposits of hydrocarbons and pitches insoluble in gasoline [1-8].

One of the diagnostics of EMN serviceability violations is the measurement of the performance of an injection device removed from the engine after checking the performance of an electromagnet. Restoration of EMN with a working solenoid is carried out, first of all, assuming that the nozzles contain surface sediments (pollution). EMN is washed using ultrasound. The degree of pollution injectors depends not only on the mileage of the car, but also on the quality of gasoline.

The purpose of the research was necessary to evaluate the technical condition of the injectors with different run times both before and after their ultrasonic washing. To solve the problem, it was considered expedient not only to evaluate the performance of the injectors, but also to establish the influence of their technical condition on the energy and environmental performance of the engine. The received data can be used in setting the terms of service timing of maintenance of the injectors. The moment of their complete replacement, regardless of the technical condition, on the recommendation of the manufacturers is 100 thousand km of run [10-12].
2. Materials and methods

Objects of research were EMA gasoline engines. A technical condition of fuel injection device was estimated by HP-6B, a device for cleaning and analysis of fuel atomizers complete with ultrasonic bathroom «Ultrasonic Cleaner». Atomizers removed from the engine have been tested. Measurements of atomizers productivity have been done in automatic and manual adjustment modes of frequency \( (n \tau) \), width \( (\tau) \) and numbers of impulses \( (N \tau) \) \([4, 13, 14]\). Mode 1 «spillage», 2 «idling», \( n = 650 \) mines\(^{-1}\) («minimum»), \( \tau = 3 \) ms, \( N_c = 2000 \) impulses; 3 «loading», \( n = 2400 \) mines\(^{-1}\), \( \tau = 12 \) ms, \( N_c = 1000 \) impulses; 4 «loading maximum», \( n = 3600 \) mines\(^{-1}\), \( \tau = 6 \) ms, \( N_c = 2000 \) impulses.

Atomizes productivity \( q_i \) is calculated by the formula:

\[
q_i = \frac{Q}{t} \tag{1}
\]

where \( Q \) - volume of fuel during measurement \( t \), ml; \( t \) - measurement time, minute.

Engine capacity and a torque have been defined on dynamometric stand LPS 2510 (CARTEC) under standard ISO 1585. The standard regulates gaugings of the power nett - real capacity of the engine. Tests have been conducted in two subroutines - in program \( P_{\text{max}} \) and \( V_{\text{const}} \). At realisation of scenario \( P_{\text{max}} \) the car speeds up at direct drive to the highest possible speed. After achievement of preliminary set threshold value of speed (for example, \( 80 \) km·h\(^{-1}\)), the stand starts to show resistance to rotation of wheels, simulating thereby real road traffic conditions of the car. During tests under scenario \( V_{\text{const}} \) the vehicle develops the greatest possible capacity at fixed (constant) speed. In program \( V_{\text{const}} \) car movement is simulated, dependence of capacity developed by a vehicle on the chosen speed is investigated.

The car with the distributed fuel injection GAZ-27040 V (GAZELLE) and engine ZMZ-406 has been tested. Toxicity of the motor has been estimated by the content of CO and \( \text{СН} \) in the exhaust gases (gas analyzer Infrakar M-2T.01). Liquids LAVR Ln 2003 and LAVR Ln 2004 have been used accordingly for atomizers cleaning and for definition of their productivity.

Both atomizers Siemens DEKA ZMZ 6354 at engine ZMZ-406 of car GAZ-27040 and EMA, removed from motors of various cars with a run \(~30\) to \(~200\) thousand km have been tested. Atomizers Siemens DEKA VAZ 20734, GM 96334808, Siemens DEKA VAZ 6238, etc have been investigated.

3. Results and discussion

Experimental data are presented in tables 1-4.

| Parameter | Run, thousand km | 150 | 60 | 30 | 0 |
|-----------|-----------------|-----|----|----|---|
| \( q_{\text{medium source}} \) ml·min\(^{-1}\) | 91.7 | 88.7 | 126.2 | 91.5 |
| \( q_{\text{medium ultrasound}} \) ml·min\(^{-1}\) | 92.3 | 89.4 | 125.6 | 91.2 |

| Parameter | Run, thousand km | 150 | 60 | 30 | 0 |
|-----------|-----------------|-----|----|----|---|
| \( q_{\text{medium source}} \) ml·min\(^{-1}\) | 9.6 | 9.5 | 12.9 | 9.3 |
| \( q_{\text{medium ultrasound}} \) ml·min\(^{-1}\) | 9.8 | 9.5 | 12.9 | 9.5 |
Table 3. Average productivity (mode of test 3) the complete set of atomizers before washing (\(q_{\text{medium source}}\)) and after washing by ultrasound (\(q_{\text{medium ultrasound}}\)).

| Parameter                  | Run, thousand km |
|----------------------------|------------------|
| \(q_{\text{medium source}}\), ml·min\(^{-1}\) | 150  | 60  | 30  | 0   |
|                            | 66.3 | 64.2 | 90.9 | 65.5 |
| \(q_{\text{medium ultrasound}}\), ml·min\(^{-1}\) | 66.7 | 64.2 | 89.6 | 65.5 |

Table 4. Average productivity (mode of test 4) the complete set of atomizers before washing (\(q_{\text{medium source}}\)) and after washing by ultrasound (\(q_{\text{medium ultrasound}}\)).

| Parameter                  | Run, thousand km |
|----------------------------|------------------|
| \(q_{\text{medium source}}\), ml·min\(^{-1}\) | 150  | 60  | 30  | 0   |
|                            | 61.1 | 59.0 | 83.7 | 60.4 |
| \(q_{\text{medium ultrasound}}\), ml·min\(^{-1}\) | 61.3 | 59.0 | 82.6 | 60.1 |

From data comparison (tables 1-4) it follows that for the complete set with an operating time of 150 thousand km atomizers productivity on all modes of testing after ultrasonic processing of devices is higher than parameter \(q_{\text{medium source}}\). For complete sets with a run below 150 thousand km \(q_{\text{medium ultrasound}}\) is equal to average productivity of atomizers before washing by ultrasound or higher than parameter \(q_{\text{medium source}}\). Similar results, namely a parameter variation \(q_{\text{medium source}}\) \(\leq q_{\text{medium ultrasound}}\) \(\leq q_{\text{medium source}}\) is characteristic and for new atomizers Siemens DEKA VAZ 20734 (tables 1-4). Such changes \(q_{\text{medium ultrasound}}\) in relation to \(q_{\text{medium source}}\) at operating time below 150 thousand km and reference (new) atomizers do not allow to make a correct conclusion about changes of atomizers technical condition after their ultrasonic processing. Therefore, both engine work testing on the dynamometric stand and measurement of CO, incomplete fuel combustion products in exhaust gases are quite reasonable.

![Figure 1. The graphic test report of the GAZ-27040 V from the ZMZ-406 engine before washing of spray jets: curve dependences of engine power (continuous lines; kW, kW) and torque (dashed lines; N\(_m\), N·m) from number of revolutions of bent shaft (U/min, ob·min\(^{-1}\)).](image-url)
Comparing values of power (N) and torque (M) engine follows (figures 1, 2) that these parameters irrespective of impact on the device of injection of ultrasound do not change. So, for example, at rotary speed of bent shaft of 2600 ob∙min⁻¹ values of power vary from 42 to 44 kW.

Changes of power (N) and torque (M) depending on rotary speed of bent shaft estimated, using data processing algorithm (the tabular test report) applied in mathematical statistics, scientific research and in calculations of reliability of products [15-18].

After searching for the maximum and minimum values of the crankshaft rotation frequency (nₜ₀), the span was calculated:

\[ \Delta x = x_{max} - x_{min} \]  \hspace{1cm} (2)

where \( x_{max} \) - maximum value of the rotational speed of the crankshaft; \( x_{min} \) - minimum value of the crankshaft speed.

Next, we determined the number of intervals (k), which can be divided, presented in the column of the tabular test protocol (nₜ₀) values:

\[ k = 1 + 3.32 \cdot \lg(N_{st}) \]  \hspace{1cm} (3)

where \( N_{st} \) is the number of parameter values nₜ₀.

To calculate the value of the interval (step) \( \delta \) used the formula Stedgers:

\[ \delta = \frac{x_{max} - x_{min}}{1 + 3.32 \cdot \lg(N_{st})} \]  \hspace{1cm} (4)

As a result of such processing 9 intervals of values of rotary speed of bent shaft have been received. Further counted for the sizes of power and torque concluded in each interval, their average size. The values of \( \Delta x \) for the 5th single tests (interval of rotary speeds of bent shaft 2000-4800 ob∙min⁻¹) averaged

Table 5 shows the average values of power and torque of the engine ZMZ-406.

From comparison given (tables 5-6) it follows that confidential intervals \( \Delta x \) of parameters \( N_{max} \) and \( M_{max} \) unlike \( Ax \) content CO and CH in the exhaust gases both before and after washing atomizers by ultrasound are blocked.
Table 5. The maximum capacity (N_{max}) and the maximum torque (M_{max}) engine ZMZ-406 of car GAZ-27040 V at tests in subroutine P_{max}.

| Parameter       | Run, thousand km | Before EMA washing | After EMA washing by ultrasound |
|-----------------|------------------|---------------------|---------------------------------|
| N_{max}, kW     | '0              | 73.6                | 69.8±1.1                        |
| M_{max}, N·m    |                 | 177                 | 165.6±3.5                       |

* - rated power as parameter N of the engine guaranteed by the manufacturer on a mode of a full throttle and the set frequency of rotation of a crankshaft; on passport data N = 73.6 kW at 4500 ob·min\(^{-1}\), M=177 N·m at 3500 ob·min\(^{-1}\).

Table 6. The content (C_{CO}, C_{CH}) in the exhaust gases (EG) carbon monoxide (CO) and products of incomplete combustion of fuel (CH) at work of engine ZMZ-406 of car GAZ-27040 V without neutralizer) in an idling mode.

| Gas          | n=850 ob·min\(^{-1}\) | n=2500 ob·min\(^{-1}\) |
|--------------|------------------------|-------------------------|
|               | Before washing EMA     | After washing EMA by ultrasound | Before washing EMA | After washing EMA by ultrasound |
| CO, %        | 1.764±0.003            | 0.618±0.006             | 2.377±0.004        | 1.577±0.008                     |
| CH, %        | (170.4±0.5) \( \cdot \) 10\(^{-6}\) | (117.3±0.6) \( \cdot \) 10\(^{-6}\) | (186.2±3.1) \( \cdot \) 10\(^{-6}\) | (128.6±0.8) \( \cdot \) 10\(^{-6}\) |

Therefore values of capacity and a torque have been analyzed, using the tool of tabular processor *Microsoft Office Excel* «the Two-selective z-test for averages», and also the t-criterion of Student, calculated by formula:

\[
t = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{(S_1^2 \cdot (n_1 - 1) + S_2^2 \cdot (n_2 - 1)) \cdot (n_1 + n_2)}}
\]

where \(\bar{x}_1 - \bar{x}_2\) - A difference of selective average values; \(S_{1,2}\) - a selective average quadratic deviation; \(n_{1,2}\) - sample volume.

According to the result of calculations it is established that distinction in compared values of atomizes capacity and a torque before washing by ultrasound is not significant. Higher values of parameters N_{max} and M_{max} the engine with EMA washed out should be characterised as a direction of growth of capacity and a torque connected with ultrasound influence effect on atomizers removed from the engine.

Values of capacity are presented in table 7 at engine testing in subroutine V_{const}.

From comparison given (table 7) it follows that at 40 km·h\(^{-1}\) the difference of values N_{v} for atomizers before washing by ultrasound is 2.2 %, at 90 km·h\(^{-1}\) 1.1 %. Such differences of capacity can be connected with a different inclination of dependences of N_{v} from speed. In fact, data processing has shown (by means of tabular processor *Microsoft Office Excel*) that in the regress equation y=a+bx factor b at a factorial variable x (speed) for dependence N_{v} from V, constructed by the results received at work of the engine with washed out atomizers, is 0.65 (kW·h)·km\(^{-1}\) or 2.34 MJ·km\(^{-1}\). For the dependence received at work of the motor with atomizers before washing by ultrasound, the parameter
b is 0.64 (kW·h)·km$^{-1}$ or 2.30 MJ·km$^{-1}$. Therefore, the capacity gain on kilometer of imitating movement of the car at speed from 40 to 90 km·ch$^{-1}$ is equal 0.04 MJ·km$^{-1}$ (1.71%).

Table 7. Capacity ($N_v$) engine ZMZ-406 of car GAZ-27040 V at tests in subroutine $V_{const}$.

| The chosen speed $V$, km·h$^{-1}$ | Run, 30 thousand km | Before EMA washing | After EMA washing by ultrasound |
|----------------------------------|---------------------|-------------------|---------------------------------|
| 40                               | 21.8                | 22.3              |
| 50                               | 30.0                | 28.9              |
| 60                               | 36.2                | 36.1              |
| 70                               | 41.8                | 41.7              |
| 80                               | 48.7                | 48.3              |
| 90                               | 54.3                | 54.9              |

4. Conclusion

Thus, as a result of the research it is established that productivity of EMA removed from engine with an operating time of 30-60 thousand km, also as well as reference (new) atomizers after their washing by ultrasound can change both productivity growth, and its decrease. It is shown that the content of CO and CH in the exhaust gases of car GAZ-27040 V (a run of 30 thousand km) at engine work (on idle turns) with washed out atomizers is lower than concentration of the specified toxic components in exhaust gases of the motor completed by unwashed out by ultrasound EMA. It is established that distinction in compared values of capacity and a torque, received in tests on the dynamometric stand in subroutine $P_{max}$, for the engine with atomizers before their processing by ultrasound is not significant. In the tests spent in subroutine $V_{const}$, the found out gain of capacity of the engine with the atomizers washed out by ultrasound is 0.04 MJ·km$^{-1}$ (1.71%).

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