Research Of Polytropic Exponent Changing For Influence Evaluation Of Actual Mixture Composition On Hydrocarbons Concentration Decreasing On Deep Throttling Operation

N M Smolenskaya*, V V Smolenskii b, I Bobrovskij c

Togliatti State University,
Beloruskaya st. 14, Togliatti, Russian Federation, 445667

E-mail: *Nata_smolenskaya@mail.ru, bBiktor.cm@mail.ru, cBobri@yandex.ru

Abstract: The purpose of this article is to present study of polytropic exponent as rating of thermodynamic process in internal combustion motor operating to deep throttling in a subcase of idle running. It is necessary to consider the influence of hydrocarbon part in exhaust gases in a process of development a new internal combustion engines especially on deep throttling operation: on combustion procedure, on irregularity of exhaust gases composition.

Introduction
Deep throttling operating mode attributes are negatives: low-pressure on bump, working and exhaust strokes, reverse emissions exhaust gases cylinders and even in intake system in the phase of valve overlap; increasing of residual gas ratio and rate of inertia; oil absorption in combustion chamber through interstice in tube rings and guide bushings of the intake valves. All this deteriorate the ignition and combustion, and lead to misfire, incomplete combustion, and to increasing of CH concentration in exhaust gases [1].

On deep throttling operation present high combustion period instability of sequential periods, this defines by changing of residual gases inertia, and so, incoming charge reactivity. Usually, periods with most comprehensive combustion follows by periods with misfire and combustion degradation. Actual working substance mixture composition is non-stable and changes from period to period, that changes thermodynamic processes of compression, burning and expansion. Hydrogen reforms hydrocarbon fuel burning conditions which is important for deep throttling operations [2, 3, 4].

Polytropic exponent
One of the thermodynamics process integral characteristic is polytropic exponent which indicates changing of heat flow direction and intensity [5, 6]. On figure 1 represented schematic changing of polytropic exponent and marked thermodynamic system main curve cusps. Point 1 indicates beginning of compression on curve piece to piece where compression polytropic exponent equivalent adiabatic exponent, which results in heating of combustible mixture from engine cylinder walls, which degrades and heat flow becomes equivalent 0 in point 1. On curve piece from point 1 to point 2 happens heat sink from contracting combustible mixture through cylinder walls. Point 2, where polytropic and
adiabatic exponents matches again, and generated heat quantity becomes equal heat quantity, degrades through cylinder walls [7].

![Figure 1 - Polytropic exponent characteristic curve actual cycle explosion engine with spark ignition](image)

On curve piece from point 2 to top dead point (TDP), equivalent 360 crank angle; combustion process on compression stroke and polytropic exponent tends to infinity i.e. isochoric process. On curve piece from TDP to point 3 polytropic exponent takes a negative value, relevant active heat emission on expansion stroke. Point 3, where \( n = 0 \) responds to maximum cylinder pressure. On curve piece from point 3 to point 5, polytropic exponent becomes equality to adiabatic exponent, occurs afterburning on expansion stroke. In point 4 polytropic exponent equals one (isothermal process means that quantity of heat returning through cylinder walls equal to quantity of heating power). On curve piece from point 5 exhaust stroke describable «graded» zone, where combustion procedure ends, and linear increase zone, where heat sink increasing because of area of the cooling surface.

Therefore, changing thermodynamics process integral characteristic research on deep throttling operating mode is actual to indicate ability to increase fuel effectiveness [1, 4, 7, 8].

**Experimental technique**

Experimental investigation was held on engine VAZ-2111 (Figure 2), upgraded with special pressure plate (thickness is 4 mm), compression ratio decrease from 9.9 to 7.5.

Indexing system was used to analyze radiant quantities of thermodynamics and combustion processes, and additional equipment was used to determine air and fuel output. META Avtotest was used to determine exhaust gas composition. Tensiometer of pressure DMVG (produced by MVG company) with proper signal multiplication. This sensor does not need cooling; it is thermostable, fast response is possible because of high natural frequency – 20 kHz. Optical sensor was used as crankshaft position sensor, and data was registrated with system L-Card L-783M: all-in-one PCI card, allowing to add a signals of megahertz range digital signals access.
Results and Discussion
Acquired data of pressure history changing shows that on idling mode there is irregularity of operation. Figure 4 represents an example of pressure changing oscillograph record with mixture composition (α) 0.988.

On main procedure on idling mode there is periods, which can be described as misfire periods, perfect combustion and partial combustion (Figure 4a). So end gas composition, and composition of air-fuel mixture depends on how went combustion on previous cycle. In the work of V.F. Kamenev [1] end gas composition in sequential cycles is not equivalent. After first cycle of perfect combustion end gases becomes inactive, and on next cycle they ballasting air-fuel mixture, so occurs partial combustion and stable flame front cannot be created. That means that in next cycle combustion will take place on all combustion space, but it’s often when behind flame front established considerable quantity of suboxide combustion residue. In next cycle they with end gases are ideal activating agents, which leads to perfect combustion.

Hydrogen as gasoline additive can lead to increasing of formation stable heat source in ignition [9], that leads to decreasing of misfire (Figure 4b).
Polytropic exponent changing analysis for 3 successive cycles shows us: perfect combustion cycle than misfire cycle and partial combustion cycle with considerable quantity of suboxide combustion residue. Figure 5 represents equitation of pressure changing (Figure 5a) and polytropic exponent in compression, combustion and expansion cycles (Figure 5b) of 3 successive cycles on idle.

Evaluation changing can be started from polytropic exponent in start of compression (part from 220 to 250 crank angle), polytropic exponent maximum in II cycle, which success I cycle (perfect combustion), which maximize uses of combustion procedure heat, reducing end gas temperature. In III cycle, polytropic exponent is minimum, that means that heat flow from cylinder walls will be much less. Evaluation polytropic exponent in main part of compression (part from 250 to 320 crank angle) shows, that polytropic exponent decreasing more in II cycle. In this cycle end gases mainly consist of perfect combustion products (from teracidic gases), and in I and III end gases consist of partial combustion products, which leads to higher polytropic exponent. Polytropic exponent averages on part from 220 to 320 crank angle as follows: in I cycle 2.066; in II cycle 2.205; in III cycle 1.894. It is notable that in I cycle sequential cycle with partial combustion end gases consist of more light atoms than in III cycle after misfire in II cycle. That can allow to expedite process of flame front establishing, indicates by fast increasing polytropic exponent after ignition.
Figure 5 – Changing of pressure (a) and polytropic exponent (b) in process compression, combustion and expansion cycles of three successive cycles on idle

Polytropic exponent changing analysis in the end of combustion cycle and on expansion in II cycle with misfire is long zone shows values lesser than 1. This means low-intensity combustion process and in I, III cycle process end faster and polytropic exponent value shows burning process completeness.
In I cycle there is heat sink in cylinder walls and in III cycle still partial combustion product is presented which decreases polytropic exponent. Average values of polytropic exponent in expansion on part from 400 to 480 crank angle as follows: in I cycle 1.713; in II cycle 1.548; in III cycle 1.635.

![Figure 6 – Hydrocarbons concentration in exhaust gases in VAZ-2111 engine on idle](image)

On figure 6 represented results on problem of decreasing of hydrocarbons concentration in exhaust gases, illustrates that hydrogen addition increases stability and burning rate. Reduction of misfire of gasoline with 6% hydrogen addition [2, 3, 9, 10] provides in average emission reduction on hydrocarbons in two times. Hydrocarbons concentration in exhaust gases in leaning more than \( \alpha = 1.15 \) explained worsening combustion terms, increasing cycle irregularity and misfire rates in proportion for gasoline with and without 6% hydrogen.

**Conclusion**

1. Polytropic exponent research showed connection between air-fuel mixture burning conditions and end gas composition and combustion irregularity on deep throttling operation. Polytropic exponent analysis in compression, burning and expansion allows to deeper understand different factors on subject thermodynamic system and quantify composition and qualities of fuel-air mixture in considerable conditions of irregularity.

2. Hydrocarbons concentration in exhaust gases by hydrogen addition decreases number of misfires and increases cycle stability on idle.

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**References**

[1] Kamenev VF, Scientific bases and ways to improve the toxic characteristics of automobile engines with spark ignition, doctoral thesis 05.04.02 NAMI, Moscow, (1996) 454.

[2] Gortyshov Y F, Gureev V M, Misbakho R S, Gumerov I F, Shaikin A P., Influence of fuel hydrogen additives on the characteristics of a gas-piston engine under changes of an ignition advance angle, Russian Aeronautics, 52(4) (2009) 488-490. Information on https://www.scopus.com/inward/record.uri?eid=2-s2.0-76449108200&partnerID=40&md5=7d22fcb28bdacfbed914ef05922e463 DOI: 10.3103/S1068799809040199.
[3] Bortnikov L N., Pavlov D A., Rusakov M M., Shaikin A P, The composition of combustion products formed from gasoline-hydrogen-air mixtures in a constant-volume spherical chamber, Russian Journal of Physical Chemistry B, 5(1) (2011) 75-83. Information on https://www.scopus.com/inward/record.uri?eid=2-s2.0-79956326816&partnerID=40&md5=8010b46bf50435298d67999d72a65398 DOI: 10.1134/S1990793111010039.

[4] Nemati A, Fathi V, Barzegar R, Khalilarya S, Numerical investigation of the effect of injection timing under various equivalence ratios on energy and exergy terms in a direct injection SI hydrogen fueled engine, International Journal of Hydrogen Energy, 38(2) (2013) 1189-1199. Information on: https://www.researchgate.net/profile/Arash_Nemati3/publication/257174777_Numerical_investigation_of_the_effect_of_injection_timing_under_various_equivalence_ratios_on_energy_and_exergy_terms_in_a_direct_injection_SI_hydrogen_fueled_engine/links/0deec536f02e74e6d3000000.pdf DOI: 10.1016/j.ijhydene.2012.10.083.

[5] Teh K.-Y, Miller S L , Edwards C F, Thermodynamic requirements for maximum internal combustion engine cycle efficiency. Part 1: Optimal combustion strategy, International Journal of Engine Research, 9(6) (2008) 449-465. Information on https://www.researchgate.net/publication/245395230_Thermodynamic_requirements_for_maximum_internal_combustion_engine_cycle_efficiency_Part_1_Optimal_combustion_strategy DOI: 10.1243/14680874JER01508.

[6] Chintala V, Subramanian K A, Assessment of maximum available work of a hydrogen fueled compression ignition engine using exergy analysis, Energy, 67 (2014) 162-175. Information on https://www.researchgate.net/publication/260211945_Assessment_of_maximum_available_work_of_a_hydrogen_fueled_compression_ignition_engine_using_exergy_analysis DOI: 10.1016/j.energy.2014.01.094.

[7] Li Y, Jia M, Chang Y, Kokjohn S L, Reitz R D, Thermodynamic energy and exergy analysis of three different engine combustion regimes, Applied Energy, 180 (2016) 849-858. Information on: http://www.sciencedirect.com/science/article/pii/S0306261916311254 DOI: 10.1016/j.apenergy.2016.08.038.

[8] Zhao Z, Wang S, Zhang S, Zhang F, Thermodynamic and energy saving benefits of hydraulic free-piston engines, Energy, 102 (2016) 650-659. Information on: https://www.researchgate.net/publication/299420570_Thermodynamic_and_energy_saving_benefits_of_hydraulic_free-piston_engines DOI: 10.1016/j.energy.2016.02.018.

[9] Shaikin A P., Galiev I R., On the effect of temperature and the width of the turbulent combustion zone on the ionization detector readings, Technical Physics, 61(8) (2016) 1206-1208. Information on https://www.scopus.com/inward/record.uri?eid=2-s2.0-84981489611&partnerID=40&md5=2a171a70052f225423d5f1082d29a746 DOI: 10.1134/S1063784216080247.

[10] Wang B, Wang Z, Shuai S, Xu H, Combustion and emission characteristics of Multiple Premixed Compression Ignition (MPCI) mode fuelled with different low octane gasolines, Applied Energy, 160 (2015) 769-776. Information on: http://www.sciencedirect.com/science/article/pii/S030626191500152X DOI: 10.1016/j.apenergy.2015.01.115.