GENERAL JONAS ŽEMAITIS
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THE DIESEL ENGINES RELIABILITY IN THE DIFFICULT CONDITIONS OF AFGHANISTAN

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Agenda

Subject: RESEARCH METHODOLOGY

2.1. General research methodology
2.2. Data collection of research objects
2.3. Weather research methodology
2.4. Engines fault distribution determination methodology
2.5. Analytical model of engines work process in highlands
2.6. Engine oil test methodology
2.7. Summary

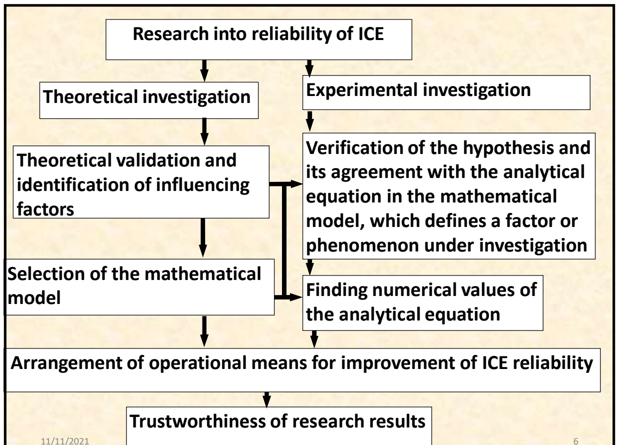
- General research methodology

General research methodology

- establishes the patterns of ICEs failing while taking into consideration the intensity and conditions of engine operation. **Research involves diesel engines 1HD–FTE, GM 6.5L and OM 366LA of thirty five cars Toyota Land Cruiser 100, M998A2, MB Unimog operated under conditions of mountainous dessert in Ghor province of Afghanistan**, and their consumed fuel and engine oils. Majority of vehicles and their engines were operated under conditions of mountainous dessert from the very beginning, except for the few of them, i.e., **starting with summer of 2005 till January 1, 2012.**

General research methodology

- Review of literature sources cited in this investigations enabled formulating goals for the research. To achieve these goals, theoretical and experimental investigations were performed having their methodological basis in development of the diagram of system under investigation and identification of the interrelations among its components. The main stage of the system under investigation is selection of the factors influencing formation of ICE failure flow. To identify these factors, the statistical data of climatic factors and phenomena occurring each month all year round are examined, and their effect is found using empirical technique. Thus, a type of mathematical model is formulated, and based on experimental results, its suitability is verified and numerical parameters of its values are found.



General research methodology

- Analysis of literature sources revealed that engine failures tend to happen one after another at particular time intervals which lead to the observation that ICE failure flow is the totality of variation in the processes of factors. The ratio of engine motor hours to time as well as variation of operating conditions in time obtain variable values which in turn evidences that engine performance indicators and behaviours thereof will be highly variable in response to the changing intensity and conditions of ICE operation.

General research methodology

- Simulation of the formation of ICE failure flow is carried out based on N. Zakharov who argues that for this purpose a structured system “Failure-Time” suits best as it enables obtaining results under variable conditions:

$$\Omega = f\left(L, t\right) \qquad (1)$$

General research methodology

- ICE motor hours and variation of operating conditions in time is the constituent comprised of the following **three components: main, periodical, and accidental.** When solving a system under investigation, the need emerges to build models of the following dependencies: variation of operating conditions; ICE operating intensity; increase in ICE run-in; the influence of increase in ICE run-in on engine failure flow; the influence of variation of operating conditions on engine failure flow; variation of the ICE failure flow in time.

General research methodology

ICE failure flow and the failure flow parameter are found from the following algorithm:

- ICE failure flow is defined as a mathematical expectancy of number of failures per particular amount of engine motor hours (mileage).
- ICE failure flow parameter is defined as a frequency rate of engine failures which is calculated by subdividing the average number of failures over the period of observation to the engine motor hours (mileage) over the same time period.

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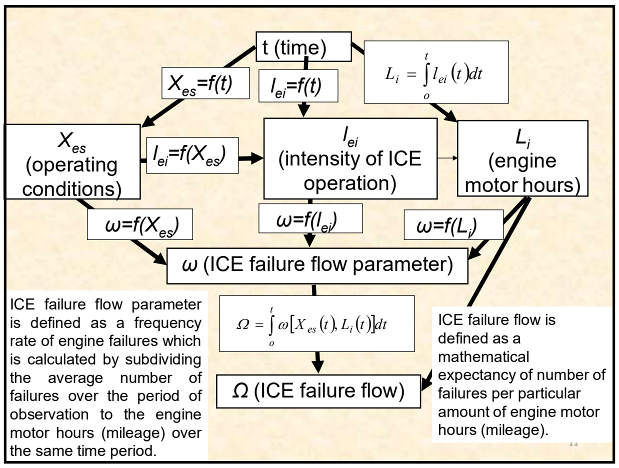

General research methodology

Surrounding environment includes all the environmental conditions under which production, operation and storage of equipment takes place.

First of all it includes climatic factors. Given the effect of the external factors on equipment, climatic factors are grouped as follows:

- **mechanical,**
- **climatic and other environmental external factors that are dependent on the geographic location, season and time of a day, etc.,**
- **biological,**
- **radiation,**
- **external factors of electromagnetic fields,**
- **factors that affect specific environment externally,**
- **thermal.**

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General research methodology

In respect of ICE operation, the climatic factor is assumed to be one of the most significant **factors leading to destabilization of engine's outside: the climatic factor includes heat and cold that are characterized by ˚C or ˚K, relative humidity, precipitation, dust and sand, solar radiation (insolation), and biological environment effect of a specific form.** Mountains are considered to belong to complicated regions in engine performance, and determine specific conditions of engine operation, consequently database is developed starting with the geographic location of the region where automotive engines are running.

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General research methodology

- Comprehensive information was collected while analyzing documentation on failures and troubles of engine systems and mechanisms, technical repairs performed during engine operation and bookkeeping. To estimate the influence of driver skills on frequency of engine failures, the questionnaire survey of soldiers on mission in Afghanistan was undertaken, and records kept in vehicle maintenance logs were analyzed.

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General research methodology

- Considering the main conceptual principle, the engine failure flow described in the research methodology was defined by the following equation:

$$\Omega = \int_{o}^{t} \omega\left[X_{es}(t), L_i(t)\right]dt \qquad (2)$$

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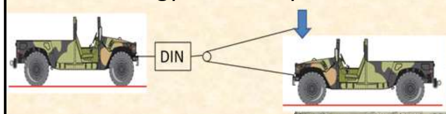
General research methodology

- Actual values of the vehicle **rolling resistance coefficient were found experimentally** using methodology offered by R. Lahno.



General research methodology

The vehicle **rolling resistance coefficient is calculated as a sum of ground resistance to motion of a rolling tire and longitudinal angle of uphill (or downhill).** Given the fact that longitudinal angle of uphill or downhill remains constant in the same road section, the rolling resistance coefficient is calculated as follows:

$$f = \frac{f_1 l_1 + f_2 l_2 + \ldots + f_n l_n}{l_1 + l_2 + \ldots + l_n} \qquad (4)$$

where: – actual values of the vehicle rolling resistance coefficient in the road section 1,2,...,n; – actual value of a vehicle rolling distance in the road section 1,2,...,n.

General research methodology

Engine **operating intensity is found from vehicle operation records and logs,** and using the same principle as in case of finding operating conditions, ICE operating intensity is then defined as follows:

$$l_{ei} = l_0 + \sum_{k=1}^{g_g} l_{Yk} \cos\left[m\left(kt_i - t_{0k}\right)\right] + l_P \qquad (5)$$

- where l_0 – constant component of the operating intensity factor which is the mean value of *X* per cycle; *k* – harmonic number; g_g – number of harmonics under investigation; l_{Yk} – fluctuation wave of the amplitude at the harmonic side *k* of the operating intensity factor, *m* – interval between t_k and t_{k+1} in degrees; t_{0k} – fluctuation phase of the initial wave in degrees; l_P – incidental part of the climatic factor corresponding to time (*t*).

General research methodology

$$l_0 = \frac{1}{n_d} \sum_{i=1}^{n_a} \frac{L_{i+1} - L_i}{t_{i+1} - t_i} \qquad (6)$$

- where n_d – number of days in a month under investigation; n_a – number of vehicles under investigation in the group; – ICE operating intensity in the interval between the month t_{k+1} and t_i, in km; – the interval of a month under investigation between the month t_{k+1} and t_i.

General research methodology

- **Increase of engine motor hours in time is the process which is dependent on the amount of engine motor hours per single time unit, or put it otherwise, on the operating intensity.** For this reason, engine motor hours over time t is expressed as follows:

$$\Delta L_i = \int_0^t l_{ei}(t)\,dt \qquad (7)$$

General research methodology

- The initial indicator of the system is time. Operating conditions of a vehicle and operating intensity change over time, while increase of the operating time of the vehicle depends on operating intensity. The variation of operating conditions and intensity of the vehicle determines its failure flow parameter. The failure flow parameter ω is calculated using the number of engine failures that occur up to the moment t:

$$\omega = \frac{\sum_1^i m_i(t+\Delta t) - \sum_1^i m_i(t)}{N(t)\cdot \Delta t}, \qquad (8)$$

where: N(t) – the number of vehicles in-operation over time t; mi(t) – the number of failures of each vehicle in operation per time interval t; Δt – average time interval of a vehicle in operation.

General research methodology

- Factors determining the failure flow are divided into three groups: climate, road conditions, operating intensity. According Zakharov [8] three types can be distinguisehed as:

  A type: (Xmin, ∞), special case (0,∞);
  B type (0, Xmax);
  C type (−∞, ∞).

- The influence of operating conditions on failure of a vehicle depending on the type of the factors can have mathematical expression as follows:

linear $\omega = a + bX$; exponential $\omega = ae^{bX}$;

power $\omega = a + bX^{c}$; square $\omega = \omega_0 + a(\overline{X} - X_{op})^2$,

where: ω – the failure flow parameter; a, b, c – parameters of the mathematical model; ω0 – initial value of failure flow parameter; X – value of a factor having an impact on the failure flow parameter.

General research methodology

According Zakharov, Rakitin, quality of the vehicles and their units is well described by adaptive mathematical models with the main factors. The failure flow parameter of a vehicle depends on air temperature, the number of rainfall days per month and the rolling resistance coefficient:

$$\omega = \omega_0 + a_t\left(T_{vid} - T_{op}\right)^2 + ce^{f_r D_k},$$

• where: wo – the lowest parameter of the vehicle failure intensity according the most favorable operating conditions; at – sensitivity of the vehicle failure flow parameter on air temperature; T*vid* and T*op* – current air temperature and optimal air temperature at which the vehicle failure intensity is the lowest, Top=6,5÷7,5 °C; c – sensitivity parameter of the vehicle failure intensity to road conditions; fv – Coefficient of rolling ressistance; D*k* – the number of days of rainfall per year.

General research methodology

- The engine **failure flow is defined as a mean number of failures over time *t*,** which is calculated from the following equation:

$$\Omega(t) = \omega \Delta L_i \tag{9}$$

General research methodology

- In case of the research under consideration, a need emerged to evaluate multiple factors simultaneously, therefore a hypothesis was made about using a multi-factor adaptive model identifying operational and road conditions as well as ICE operating intensity:

$$\omega = \omega_0 + a_k K_N^2 + cf + bl_{ei} \qquad (10)$$

where – the least parameter of ICE failure intensity, corresponding to the most favourable conditions of engine operation; – the sensitivity of the parameter of ICE failure intensity to the adversity of engine operation; – the sensitivity coefficient of the ICE failure intensity parameter to road conditions; – the sensitivity coefficient of the ICE failure intensity parameter to engine operating intensity; – current adversity of ICE operation; – rolling resistance coefficient; l_{ei} – the ICE operating intensity.

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Data collection of research objects

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Geographical Location of Afghanistan

- Afghanistan is located in Central Asia and has borderlines with **Tadzhikistan, Uzbekistan, Turkmenistan, Iran, Pakistan and China.** Afghanistan lies in the North-Eastern part of Iran Mountain range with high sierras and valleys between mountains. Eastern regions of Afghanistan are separated by a high mountain range Hindu Kush stretching from southwest to northeast with peaks of 4000–5000 m in height, Vahanski Range of 6000 m in height, and its Hashack Mountain near the borderline of Pakistan is the highest point in the State – 7485 m. The highest areas of mountains, especially those in north-eastern part, are covered by different types of glaciers.

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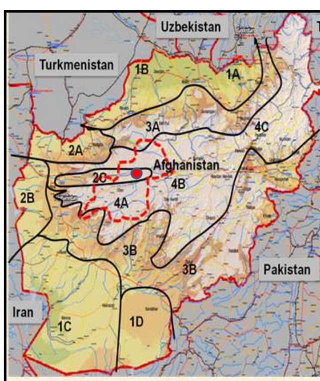
Geographical Location of Afghanistan

- A huge impenetrable mountain range Hazarajat unfolds to the west from Hindu Kush with its mountaintops rising as high as to 3000 m., and some peaks achieving a height of 4000 m. Here, in these mountains, an active rock weathering takes place in result of which mountains decay, and debris as well as large blocks form. A system of lower mountain range Paropamiz run to the west and east-west from Hazarajat Mountains showing a form of creeper with the length of 600 km and width of 250 km. Two main ranges of this mountain system – Safedhok in the north, and Siahkok in the south – are separated by river Gerirud and its valleys.

Geographical Location of Afghanistan

- A wide Baktrijsk plain lies in the north of Afghanistan with the incline running towards the valley of Amu Darya River. The surface of the plain Hindu Kush and foothill of Paropamiz Mountains is comprised of several interchanging layers of aqueous and metamorphic rocks with the prevailing yellow soil sediments; the foothills cross many rivers. In the north, Baktrijsk plain transforms into a sand desert. There is a hilly horst with the height of 500–1000 m. in the south-west of Afghanistan, and a huge area is occupied by the sand desert Registan and clay deserts Seistan and Dasht-i-Margo. There is a plateau of 1000 m in height in the south-east area of Afghanistan with several oasis, the largest of which lies in surroundings of the city of Kandahar.



Map of geographical location of Afghanistan. Regions of deserts: Oxus basin (Amu Darja) (1A), Kara-Kum (Garagum), Badghyz and Karabil (1B). Clay deserts: Seistan, Dasht-e-Margo and Dasht-i-Arbu (South, South-West Afghanistan desert) (1C), Registan, South-East Afghanistan Sandy Desert (1D). Regions of semi-deserts: Khorassan (2A), part of Persian (Iran) desert (2B), **valleys of semi-deserts of the Afghan Mountains (2C)**. Regions of hills, semi-deserts and lower mountains that can be passed through: regions of Safedhok and Circum Oxiani-Hill (3A), and Siahkok (3B). Mountainous regions: **Chorat (4A), Paropamiz and Hazarajat Mountains (4B),** alpine plain surface Hindu Kush (4C), Pamir high-mountainous region (4H).

Data collection of research objects

- The number of test engines that have not been overhauled is determined by the dependence of:

$$N_{vp} = \frac{z_\beta^2 [v(t)]^2}{\varepsilon_1^2},$$

- where: v (t) is the coefficient of variation; ε1 is the relative deviation of the test results; zβ is a number characterizing the reliability of the test results.

Data collection of research objects

- According to NATI (Transport Technology Research Institute), the values of coefficients of variation of field test results before overhaul of engines are v (t) = 0.36 ÷ 0.5, confidence probability β = 0.6 ÷ 0.95, then zβ = 0.85 ÷ 2.18; higher values of zβ apply in the event of a risk to the health and life of supervising staff; zβ = 1.28 is recommended for accelerated VDV testing. The study was performed in VDV operation in difficult conditions, therefore its value should be 1.28≤zβ≤2.18, ε1≤0.2 is recommended for VDV reliability indicators during engine modernization and ε1≤0.3 during new design. For the calculation of the number of diesel engines required for testing according to formula (2.27), the following values were chosen v (t) = 0,4, zβ = 1,4, ε1 = 0,2 and the results are given in Table.

Pasirinkti duomenys	$v(t)$=0,36	z_β=0,85	ε_1=0,2	$v(t)$=0,4	z_β=1,4	ε_1=0,2	$v(t)$=0,5	z_β=2,18	ε_1=0,2
Engine number	2,34			7,84			29,70		

Data collection of research objects

Before starting the test of the engine of each car tested, the following documents shall be submitted: engine passport and its characteristics, construction, operation and maintenance instructions, assembly sheets. The quality of engine repair and maintenance work is determined by the quality of the use contract, the quality of materials and parts, the completeness of the engine operating instructions, the quality of the work of the maintenance personnel under the control of the head of the repair department. In my test case, the engines were operated in deviation from the manufacturer's requirements. During the tests, the resource consumed by each engine, the date and cause of the breakdown, spare parts used, fuel and engine oil nomenclature and entries in the car limit books were recorded. In the event of a fault, the signs of the fault, the causes of the fault and the method of remediation were also recorded, and photographs were taken. Disassembly and assembly of engine assemblies, replacement of defective parts, adjustment of systems related to replacement of parts were used for engine failure search and elimination operations.

Data collection of research objects

The technical condition of the repaired units and parts is assessed as follows: tightening of joints with a torque wrench and external inspection, change of factory adjustable gaps according to the changed gauge sizes, sealing elements according to fluid penetration, integrity (without signs of cracking), degree of material elasticity and wear; these data are compared with the manufacturer's documentation. Measurements of engine parts were performed in accordance with the manufacturer's repair documentation with the recommended measuring equipment. The average dimensions given in the parts manufacturer's drawings are used as the primary data for determining the degree of wear. A part is suitable for use if its wear and general condition is less than the critical dimension allowed by the manufacturer and its residual life until the next maintenance is not less than the planned life of the engine part.

Taking into account the available research possibilities and limitations, a study was carried out in the Afghan desert conditions, which determined the durability of engine design, its systems and mechanisms, diesel engine resources and failure distribution laws, engine power before the first overhaul, , average engine life before failure, engine operating time to write - off. All tests were performed under real operating conditions. Due to the restriction of the disclosure of official information with the characteristics of state secrets, the results of the research on the indicators of reparability and complex reliability of the engine are not provided.

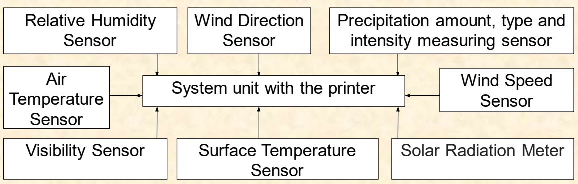
Weather research methodology

Weather research methodology

- For the purpose of assessing 24-hour changes in climatic and other environmental factors having effect on the equipment operated in Afghanistan from the outside, **data collected by the Meteorological Institute under Transport and Tourism Ministry of Democratic Republic of Afghanistan** (for the periods of year 1939–1953, 1958–1984, and 1987–1996) and statistics of meteorological data recorded by Air Traffic Management Centre of Ghowr Province restoration group using a meteorological observation system ***Vaisala TacMet Tactical Meteorological Observation System MAWS 201M* with the software *MIDAS IV Tacmet* (for the period of 2005-2010)** were used. This system serves 24 hours a day to detect and record meteorological data every 30 minutes.

Weather research methodology

This equipment is used to detect and record meteorological data at one minute intervals 24h a day. Fig. shows the structural scheme design of the weather station of the Chagcharan Air Traffic Control Centre in Ghor Province (2005–2012).



Weather research methodology

The daily mean value of the climatic elements, excluding air pressure, is calculated as the arithmetic value of the eight measurements taken every 3 hours. from 00.00 UTC to 24.00 UTC, average. The temperature is measured with thermometers (Celsius accuracy ± 0,1 ° C) at the indicated UTC hour. The minimum temperature is measured at 00.00 UTC, the maximum temperature is 12.00 UTC, the maximum temperature is on the day and the minimum temperature is on the Celsius scale at night. The annual average temperature is calculated as the arithmetic mean of the twelve months. The average temperature of the three coldest or warmest months is calculated as the arithmetic mean of the three-month periods of the respective season. The monthly average temperature is calculated as the arithmetic mean of the total number of days in the month. The annual air temperature amplitude is the difference between the highest and lowest annual air temperatures.

Weather research methodology

The daily mean **air pressure** is calculated as the arithmetic mean of four measurements taken every 6 hours, starting at 3.00 UTC and ending at 21.00 UTC.The amount of daily precipitation is determined as the amount of precipitation that falls in 24 hours from 00.00 UTC.

Drops of water (ice crystals) forming from the atmosphere or on the surface of the earth are called precipitation. Precipitation is the layer of water that forms on a horizontal and impermeable surface if it is not absorbed into the soil, evaporates or drains to lower places. Precipitation is measured in millimeters.

Relative humidity is the ratio of the actual vapor content of water to the potential vapor content at a given temperature. Humidity is measured with hygrometers and psychrometers.

Weather research methodology

- For the reliability study the following factors were selected and statistically processed: air temperature and its duration, solar radiation, air pressure, average wind speed and its duration, relative humidity and precipitation and fall time.
- The meteorological database used in the research was created in years including the following units of measurement: temperature (°C), precipitation (mm), wind speed (m/s), air pressure (Pa), time used (hour whose reference point is set in UTC+4,5).
- Operating conditions of a vehicle include all the factors that affect its performance. An objective indicator is the climate factor. This is to be understood as the sum of the factors X_1, X_2, ..., X_n of operating conditions X, in which each factor has its own specific numerical value .

Weather research methodolog

- As operating conditions change in time, the climatic factor might be figured in the form of harmonic series as follows:

$$X_{es} = X_0 + \sum_{k=1}^{g_g} X_{Yk} \cos[m(kt_i - t_{0k})] + X_P \qquad (3)$$

where X_0 – constant component of the climatic factor which is the mean value of X per cycle, k – harmonic number, g_g – number of harmonics under investigation, X_{Yk} – fluctuation wave of the amplitude at the harmonic side k of the climatic factor, m – interval between t_k and t_{k+1} in degrees, t_{0k} – fluctuation phase of the initial wave in degrees, X_P – incidental part of the climatic factor corresponding to time (t).

Weather research methodolog

- In order to determine the concentrations of particulate matter (PM) in the vehicle environment, an experiment was performed by collecting PM samples by filtration. PM samples were collected using aerodynamic probes. The aim was to identify two fractions, DKD and KD4. ∑KD samples were collected with polypropylene cartridges (SKC Inc. USA), KD4 samples were collected with KD4 cyclones (KD4 - KD fraction up to 4 µm) (SKC Inc. USA). Air was pumped using built-in air pumps (model 224PCXR4, SKC Inc, USA). The flow rate of the intake air is 2.2 l / min, the air flow is measured with a pump rotameter. PM samples were collected on cellulose ester filters (MCE, SKC Inc. USA) with a diameter of 25 mm and a pore size of 0.8 µm.PM concentrations were measured at three measurement sites under different conditions. The first location for measuring PM concentrations is the territory of the military unit, ~ 1 m and ~ 0.3 m above the ground.

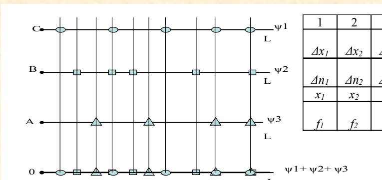
Weather research methodolog

- The second stationary PM measurement location was a vehicle repair shop, PM measurements were performed at a height of ~ 1 m. In the first case, PM concentrations are measured during work, in the second - during non-working hours. In the third case, PM concentrations were measured in the vehicle column; from a moving vehicle at a height of about 1 m above the ground. The measurements were performed on the first vehicle in the column and on the vehicle in the middle of the column. The average speed of the column was 15–20 km / h, the column consisted of 3 heavy vehicles and 14 light vehicles. Measurements were performed in 2009. November 11-14 During the measurement period, the average temperature was 2.8 ºC, the average wind speed was 1.6 m / s, and the relative humidity was 31%. The collected sample filters were transported to Lithuania, where gravimetric analysis was performed in the KTU laboratory. Chloride concentrations in road dust were determined using ISO 9297: 1998. The sulphate content was determined by turbidimetry in accordance with ISO 11048: 1995. The pH of the test road dust samples was determined according to ISO 10390: 2003.

Engines fault distribution determination methodology

Engines fault distribution determination methodology

- In order to determine the law of distribution, a variation line is initially created based on the data of the study result - initial data on the values of random variables obtained by observation (in ascending order of values). The variation line shows the limits of random variation. It indicates the size of each interval and the limits of random variation. The size of each interval is also given, as well as the numbers (frequencies) mh of random values, which fall into the interval i from the total number n.



1	2	3	4	j	k	Σ
Δx_1	Δx_2	Δx_3	Δx_4	Δx_j	Δx_k	$\sum_{i=1}^{k} \Delta x_i = l$
Δn_1	Δn_2	Δn_3	Δn_4	Δn_j	Δn_k	$\sum_{i=1}^{k} \Delta n_i = n$
x_1	x_2	x_3	x_4	x_j	x_k	-
f_1	f_2	f_3	f_4	f_j	f_k	$\sum_{i=1}^{k} \hat{f}_i \cdot \Delta x = 1$

Engines fault distribution determination methodology

$$k = \frac{(L_{\max} - L_{\min})}{\Delta L}, \quad \Delta L = \frac{(L_{\max} - L_{\min})}{(1 + 3{,}322 \cdot \lg n)}, \quad p_i = \frac{\Delta n_i}{n_k},$$

$$L_{vid} = \frac{\sum_{i=1}^{N_v} L_i}{N_v}, \quad \sigma = \sqrt{\frac{\sum_{1}^{n} (L_i - L_{vid})^2}{n-1}}. \quad v_t = \frac{\sigma}{L_{vid}}. \quad \chi^2 = \sum_{i=1}^{k} \frac{\left(f - \hat{f}\right)^2}{f},$$

- The law of distribution can be selected according to the magnitude of the coefficient of variation: if vt <0.33, the normal law of distribution is selected; if vt> 0.33, the Weibull distribution law is chosen; 0.45 <vt> 0.6 - the relay distribution law is selected; 0.9 <vt> 1.1 - the exponential law of distribution is selected.
- The conformity assessment of the distribution law is performed using the $\chi 2$ - Pearson compatibility criteria.

Analytical model of engines work process in highlands

Analytical model of engines work process in highlands

Experience of technical operation in Afghanistan has highlighted the increased failure rate of the engines 1DH–FTE, GM 6.5L, the OM 366 LA and decrease in performance of overall engines reliability . One of engine reliability indicators is its resource, which depends on the engine operating conditions. In view of the current theory of friction and wear, parts wear rate **Vd** has such a dependence:

$$V_d = f(P, V, C)$$

Where P – normal pressure between the contacting surfaces, V – relative speed of movement of the rubbing surfaces, C – friction conditions.

Analytical model of engines work process in highlands

Increase rate of maximum pressure (dP/dϕ)max and rate of average pressure (ΔP/Δϕ) during an engine fuel combustion process in diesel engine cylinders is called the fuel burning rate. Increase in increase rate of the maximum pressure (dP/dϕ)max and rate of average pressure (ΔP/Δϕ) causes increasing of the engine power and productivity, also increasing maximum pressure Pz of the diesel operation cycle, increasing loads of the engine crankshaft mechanism and piston – cylinder mechanical group, and the diesel work is accompanied by specific diesel noise sounds, typical for to rapid combustion of diesel fuel. This process influences the wear of engine parts.

Rate of maximum (dP/dϕ)max and average (ΔP/Δϕ) pressures increment rate during engine fuel combustion process in diesel engine cylinders is calculated by a formula:

$$\left(\frac{dP}{d\varphi}\right)_{\max} = \frac{6 \cdot n \cdot 10^{-3}}{\sqrt{K_T \cdot \rho}} \cdot \frac{P_Z - P_C}{\varphi_1} \cdot \left(i \cdot \tau_1 \cdot \frac{100}{C_N}\right)^{\frac{2}{3}}$$

Where n – engine crankshaft rotation speed, min^{-1}; KT – factor characterizing fuel performance; ρ – fuel densi-ty, g/cm3; PZ – maximum cycle pressure, MPa; PC – air compression end pressure in cylinders, MPa; ϕ1 – fuel igni-tion delay, deg.c.r.; i – the relative fuel evaporation rate during fuel ignition delay period; τ1 – the ratio of fuel igni-tion delay period and fuel injection period; CN – fuel ce-tan number; ϕ2 – period of fuel rapid combustion, deg.c.r. (deg.c.r. – angle of degree of engine crankshaft rotation)

Analytical model of engines work process in highlands

Watson factor characterizing fuel performance:

$$K_T = \frac{1{,}216 \cdot \sqrt[3]{T_{50}}}{\rho_{15}^{15}}$$

Where T_{50} – fuel 50 % volume distillation temperature, °*K*; ρ_{15}^{15} – fuel density at temperature *15°C*, *g/cm³*.

Fuel evaporation ratio is calculated as follows:

$$i = \frac{m_{VIK}}{g_{CK}}$$

Where m_{VIK} –fuel quantity vaporized over fuel ignition delay period, *kg*; g_{CK} – fuel quantity, injected into engine cylinder, over cycle, *kg*.

Analytical model of engines work process in highlands

In determining the period of the first phase the model of relative fuel ignition delay is used:

$$\tau_1 = \sqrt{6 \cdot n \cdot 10^4} \cdot \left[\frac{\ln\left[\sqrt{\rho}\left(\frac{\varphi_{IK}}{K_T} - \Theta_{BT}\right)\right]}{a} + \left[\frac{A}{2} \cdot \sqrt{\rho} - \frac{\left(1 - \frac{\varphi_{IL}}{\varphi_{IK}}\right)}{K_T}\right] \cdot \frac{\sqrt{a_1 - 1}}{\Psi \cdot \varphi_{IK}} \right]$$

Where ϑ_{BT} – non–dimensional temperature at the beginning of fuel injection; *A* – factor of fuel properties; a, a_1 – diesel engine and fuel injection system structure weightings; *Ψ* – assessment factor of ratio of physical and chemical rates; ϕ_{IL} – fuel injection period (using fuel injection system features of real engines *1DH–FTE, GM 6.5L, OM 366 LA*), *deg.c.r.*; ϕ_{IK} – the factory fuel injection angles (fuel injection system angles of real engines *1DH–FTE, GM 6.5L, OM 366 LA*), *deg.c.r.*

Analytical model of engines work process in highlands

Non–dimensional temperature θBT, factor of fuel properties A; assessment factors of structure of diesel engine and fuel injection system a, a1, Ψ– assessment factors of ratio of physical and chemical rates are calculated as follows:

$$\Theta_{BT} = \frac{1}{(4.38 + 2.29 \cdot lg T_{50}) \cdot \frac{T_{50}}{T_C} \cdot \sqrt{K_1} + 25 \cdot \left(\frac{1}{C_N} - \frac{1}{100} \right)} \qquad A = \frac{K_T \cdot T_{50}}{C_N \cdot 273} \qquad a = \frac{K_Q}{\Theta_{BT}}(a_1 - 1)$$

$$a_1 = \frac{(V_{IP} - V_{DK}) \cdot (n_1 - 1) \cdot \varphi_{IL} \cdot C_V \cdot \lambda_H \cdot l_{0D} \cdot T_{IP}}{\varphi_{pp} \cdot i \cdot q_T \cdot V_{IP} \cdot K_1} \qquad \Psi = \sqrt{a} \cdot e^{2a}$$

Where T_{IP} – temperature in engine cylinder at the fuel injection moment, *K; K_Q* – non–dimensional heat transfer characteristic; V_{IP} – cylinder volume at the fuel injection moment, m^3; V_C – cylinder combustion chamber volume, m^3; n_1 – compression ratio of polytrophic; C_V – air specific heat (heat capacity), *KJ/kg·K*; λ_0 – excess air ratio at an altitude $H=0$ *m*; l_{0D} – the quantity of air needed to completely burn one kilogram of fuel, *kg*; q_T – quantity of heat required to vaporize and overheat a kilogram of fuel by injection into the compressed air in engine cylinder at temperature T_C.

Analytical model of engines work process in highlands

Special factor that affects engine performance in alpine terrain is lower air density, which thus reduces the air intake volume to the engine cylinder during the cycle, therefore assessment at the beginning of compression cycle at height *H* of air pressure P_{AH} is made by the empirical formula:

$$P_{AH} = \mu \cdot \left(P_0 - \frac{\Delta P_{A0}}{\beta} \right)$$

Where P_0 and ΔP_{A0} – air pressure and loss of air at sea level $H=0$ *m*; μ – factor of difference of temperatures; β – atmospheric pressure difference coefficient

In the case of the engines used in Afghanistan, when the settings of engine manufacturer are not changed that match the engine operation at sea level at its nominal load, it leads to loss of excess air factor. Change of this ratio rising up in the mountains, with unchanged settings of fuel system set by an engine manufactureare evaluated by the equation:

$$\lambda_H = \lambda_0 \cdot \frac{\mu}{\sqrt{\beta}} \cdot \left(\frac{\pi_{KH}}{\pi_{K0}} \right)^{\frac{1}{n_H}}$$

Where λ_H – excess air factor at altitude *H* above sea level, π_{KH} – air pressure increase rate in compressor above sea level, H; π_{K0} – air pressure increase rate in compressor at altitude $H=0$ *m*; n_H – air compression polytrophic ratio in compressor.

Analytical model of engines work process in highlands

Non–dimensional heat transfer characteristic (K_Q), heat amount required to vaporize and overheat a kilogram of fuel by injection into the compressed air in engine cylinder at temperature T_C (q_T), cylinder volume at the fuel injection moment (V_{IP}), fuel ignition delay (φ_1) and fuel rapid combustion period (φ_2), and cycle maximum pressure (P_Z) are calculated as follows:

$$K_Q = \frac{i \cdot q_T}{C_V \cdot \lambda_0 \cdot l_{0D} \cdot T_C} \cdot \sqrt{K_1} \qquad q_T = C_D \cdot (T_{50} - T_P) + L_{GD} + 0{,}5 \cdot C_D \cdot (T_{IP} - T_{50}) \qquad \varphi_i = \tau_i \cdot \varphi_{IL}$$

$$V_{IP} = \frac{V_h}{2}\left[\frac{\varepsilon + 1}{\varepsilon - 1} - \cos\varphi_{PP} + \frac{\lambda_1}{4}(1 - \cos 2\varphi_{PP}) \right] \qquad \varphi_2 = \left(\frac{C_N}{100} \right) \cdot \rho \cdot \left(\frac{\varphi_{IL}}{i} \right) \qquad P_Z = P_C + 5{,}39 \cdot 10^{-4} \cdot \frac{m_{VIK} \cdot H_Q \cdot (n_1 - 1)}{V_C}$$

Where T_{IP} – temperature in engine cylinder at the fuel injection moment, *K; K_Q* – non–dimensional heat transfer characteristic; V_{IP} – cylinder volume at the fuel injection moment, m^3; V_C – cylinder combustion chamber volume, m^3; n_1 – compression ratio of polytrophic; C_V – air specific heat (heat capacity), *KJ/kg·K*; λ_0 – excess air ratio at an altitude $H=0$ *m*; l_{0D} – the quantity of air needed to completely burn one kilogram of fuel, *kg*; q_T – quantity of heat required to vaporize and overheat a kilogram of fuel by injection into the compressed air in engine cylinder at temperature T_C.

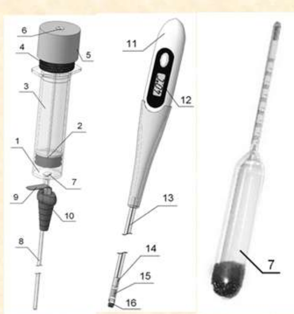
Engine oil test methodology

Engine oil test methodology

Another element of engine design that affects engine failure and durability is the oil used in the engines. The engines of all cars operate under high dynamic loads and emit a large amount of heat during operation. The engine oil must reduce friction between the friction parts of the engine, reduce their wear and maintain a certain thermal balance of the engine. In the operation of engines, the oil acts as a collector of wear products and various pollutants, making the used engine oil a complex for the oxidation of complex colloidal hetero-organic carbon-hydrogen mixtures, a large number of different chemical compounds from the base oil, oil additives, various polydisperse pollutants and oil. All this can be seen in the key indicators of engine oil quality. Thus, the engine oil used to operate the engines is a specific source of information about the thermodynamic, chemical, and tribilogy processes that took place between the friction surfaces in the engine system. Changes in the technical condition of the engine are reflected in the quality of the engine oil.

Engine oil test methodology

Engine oil tester kit: user manual, tester, cleaning supplies, filter paper, glycerin package, searchlight, magnifying glass, oil activity scale setting standard, aerometer, floats, copper clamps.



Engine oil test methodology

When the used engine oil has reached a critical change in the oil properties, the recommended rejection values are given in Table.

Parameter	Value(Baltėnas 1998)	Value(Zorin 2005)
Oil viscosity change,% Decrease Increase	 Up to 25 Up to 25	 Up to 35 Up to 20
Content of impurities insoluble in petrol, %	Not more than 2.0-5.0	Not more than 3.0
Water content in oil,%	Not more than 0,5	Not more than 0,3
Antifreeze content in oil,%	Not more than 0.3-0.4	Not more than 0.3-0.4
Fuel content in oil,%	Not more than 5	Not more than 0,8
Sample of oil stains on filter paper	non	Not less than 0,3 to 0,35 contractual units
Oil flash temperature drop	Not more than 25%	Not more than 20 ° C
Number of alkali oils, mg KOCH / g	1.0-3.0	1.0-3.0

Engine oil test methodology

The thermal load of motors affects the design properties of the motors used. When the air temperature rises by 10 ° C, the temperature of the engine pistons rises by 2-4 ° C. An increase in the effective gas pressure of 1 kg / cm2 during fuel combustion increases the engine piston temperature by 10-11 ° C, a delay in the ignition of the combustible mixture by one degree of crankshaft increase the engine piston temperature by 1-4.5 ° C; a 10 ° C increase in the temperature of the coolants increases the temperature of the engine pistons by 6-8 ° C; the use of closed antifreeze cooling systems with an operating temperature of 110–115 ° C increases the temperature of the engine pistons by 10–20 ° C (Grigorjev 1981).When the operating temperature of the engine oil increases by 10 ° C, the oxidation rate of the oil doubles. If the engines are equipped with forced crankcase ventilation, the operating conditions of the engine oil become even more difficult (Grigorjev 1981; Baltėnas1998).

Engine oil test methodology

The specifics of car use in Afghanistan do not preclude water barriers either. This results in increased water content of the engine oil. In the highlands of the Afghan desert, the fuel combustion process in the engine cylinders takes place at lower values of the excess air coefficient, which increases the temperature of the burnt combustion mixture, and the gas bursting into the crankcase is hotter than in the plain.The reasons listed above alter the physical and chemical properties of engine oil, resulting in the formation of organic and inorganic contaminants in the oil. The main oil pollutants in the operation of engines are organic carbon and hydrogen and inorganic wear products of friction engine parts.

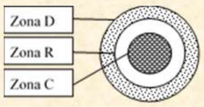
Organic pollutants

Inorganic pollutants

Engine oil test methodology

Physics-chemical characteristics was determined:

- **The viscosity of the oil;**
- **Oil density;**
- **Examination of a sample of oil stains on a filter paper.**



This method is used to estimate the remaining oil use resource based on the oil stain on the filter paper. This test is quite informative and simple - it is a simplified method of paper chromatography. When the oil is applied to the filter paper, the drop spreads and leaves an oil-specific stain - the core C is in the center, a narrow ring R is formed around the center from the oil-insoluble particles, the diffusion area D spreads from the oil . This method makes it possible to estimate the size of the particles dispersed in the waste oil, the effectiveness of the remaining additives and the suitability of the oil for further use.

- **the dependence of the rate of change of the viscosity of the oil on the temperature during heating of the oil.**

Used oil examination based on its stain on the filter paper

Score	Areas of an oil stain			Oil condition
	C	R	D	
1	Light grey to white	Grey	Light grey	Excellent
2	Light grey to grey	Grey to dark grey	Grey	Excellent
3	Grey	Dar grey	Grey to dark grey	Good
4	Dark grey to black	From dark grey	Dark grey to black	Good
5	Black with individual glossy small stains	Black	Dark grey to black	Satisfactory
6	Black, slightly glossy	Black	Dark grey to black	Satisfactory
7	Intense black, glossy	Black	Dark grey to black	Bad
8	Intense black, highly glossy	Black	None	Satisfactory

Summary

This lecture analyzes the chosen method of engine reliability testing, which is applied in real operating conditions of diesel engines in the mountains of Afghanistan.

A new engine reliability test method is proposed to evaluate the influence of operating conditions and operating intensity on the formation of engine fault flow parameters.

According to N. Sakharov, A. Rakitin and others researchers, the time dependence of the engine fault flow parameter is separated from the output dependence of the engine fault flow parameter. It is proposed to describe the VDV fault flow parameter according to an adaptive equation consisting of the sum of three simple dependencies.

Summary

An analytical model of the car's VDV work process in the highlands has been developed, which allows to evaluate the influence of the used fuel and the difficult operating conditions of the engine on the thermodynamic process of the engine. A method for testing engine oil using an oil tester is presented.

Based on the performed analysis, a methodology has been developed that allows to obtain results for determining the operational reliability of diesel engines and to evaluate the influence of climatic factors on the operational reliability of engines. The methods used to determine the reliability of the experimental studies (results) and the evaluation of the scatter allow to check the accuracy of the study results.