Influence of the parameters of a forestry machine-tractor unit on the hourly fuel consumption of a diesel engine

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Abstract. To improve the quality of the design of a forestry machine-tractor unit (MTU), it is necessary to develop and use various methods for assessing the operational efficiency of MTU, which is particularly relevant at the design stage. The manuscript examines the influence of the parameters of a forestry MTU on the hourly fuel consumption of a diesel engine. The speed of movement of the MTU was chosen as an operational parameter, and the suspension rigidity was chosen as a design parameter. In ploughing mode, diesel fuel consumption per hour is determined for dynamic loads by component: from resistance when moving up-hill; from the dynamics of the soil layer turn-over by the plough; from MTU inertial forces; from oscillations of the MTU suspension in the longitudinal-vertical plane; from mechanical losses in friction pairs of the engine, as well as its total value for different values of suspension stiffness. The maximum values of the total dynamic component of the hourly fuel consumption in ploughing mode are observed at frequencies close to 2.5 s⁻¹, that is, close to its own energy-consuming frequency of oscillations of the rotational speed of the crankshaft of the SMD-20T.04 engine. To improve the fuel efficiency of an MTU diesel engine, it is necessary to introduce a correction device into the design of a high-pressure fuel pump (HPP). As a corrective device, it is advisable to use an oscillation damper of the rail of the fuel pump (RFP). The vibration damper is used to reduce the amplitude of oscillations of the rail and the negative effect of the hydrodynamic force on the quality of the speed control process. Its advantage lies in the fact that, while damping, it reduces the effect of hydrodynamic force during fuel cut-off and, to a lesser extent, provides resistance when moving RFP in the direction of increasing the cycle fuel supply.

1. Introduction

Currently, the methods of statistical dynamics [1, 2], the scientific base of agricultural mechanics [3] and the existing theories of MTU [4, 5] are used in design and production of forestry machines and aggregates.

Studies of the operation of diesel engines, power transmissions and MTU units in different modes in most cases are limited to their dynamic loading and are not concerned with the energy performance associated with fuel and oil consumption, as well as with power consumption. Therefore, the task of energy assessment of the dynamic processes of MTU, and the theory and practice of reducing energy consumption [6, 7] remain very relevant. Minimizing the energy required to perform technological operations reduces the amount of fuel required and the operating costs of MTU, which ultimately reduces the cost of forestry and reforestation activities.
Therefore, the task is to study the influence of the operational and design parameters of MTU on the hourly fuel consumption of a diesel engine. The development and practical use of various methods of estimating MTU fuel consumption are relevant at the design stage and can improve the quality of design of MTU [8-16].

2. Methods
The models of functioning of a forestry MTU in different modes were built in the mathematical environment “MathCAD”, and Microsoft Excel was used for processing the results and plotting. The calculation method is described below.

The main external forces in the models are: the terrain of a clear cut area, defined by the correlation function and spectral density; physical and mechanical properties of soil; and MTU speed. The unsteady nature of the forces of resistance to the motion of MTU described by an ergodic stationary random process is modelled for the entire frequency spectrum of the input load moment. The article discusses the ploughing mode of operation of a tractor LHT-100 with a PKL-70 plough on light soils.

For MTU under consideration, a sufficient amount of operational indicators has been accumulated which are necessary for estimating modeling errors, since it has been widely used in forestry and reforestation works.

2.1. Analytical expressions for determining the hourly fuel consumption of an MTU diesel engine in ploughing mode
The expression for hourly fuel consumption, derived according to the formula of V P Goryachkin [3] for the tangential force of MTU in ploughing mode, has two components; regular $\hat{A}_0^P$ and variable $\hat{A}_p(\omega)$, recorded in the operator form (when $s = j\omega$):

$$B_0^p = E_i i_{\eta_m} \left[ \frac{R}{i_{\eta_m}} \left( A_i^1 + A_2 + A_3 n_0^2 \right) + D_1 (a_1 + b_1 n_0) \right];$$

$$B_p(\omega) = E_i \cdot \hat{A}_{\eta_m} \cdot \omega \cdot \left| U_1(j\omega) \right| \left[ \frac{R}{i_{\eta_m}} \left( A_1^p + A_2 + 3 A_3 \right) \left| U_1^2(j\omega) \right| + 2 f_{rf} \cdot \Theta_p(j\omega) + 2 A_4 \omega \cdot \left| U_1(j\omega) \right| \right] + D_1 \cdot \left( \frac{a_1}{P_{mn}} \right) \cdot \left( \frac{4 \omega^2 + \gamma^2}{\omega^2 + \gamma^2} \right) \cdot \left| G_6(j\omega) \right| + 2 b_1 \omega \cdot \left| U_1(j\omega) \right|] \right] \right].$$

where, $E_i = \frac{3.6\pi}{30 n_0 H_c}$; $A_1^p = mg \sin \alpha + f_{rf} m_t g \cos \alpha$; $A_2 = f_{pf} m_p g \cos \alpha + k_f ab$;

$A_3 = \left( \frac{\pi R}{30 \eta_m} \right)^2 \xi a b$; $A_4 = \frac{\pi R}{30 \eta_m} m$; $D_1 = \frac{V c i_e}{\pi \tau_c}$,

where, $n_0 = 0.8 n_n$; $n_n$ - nominal frequency of rotation of the crankshaft of a diesel engine; $R$ is the radius of the leading sprockets; $i_t$ - transmission ratio; $\eta_m$ - mechanical efficiency, $\eta_m = \eta_{fr} \cdot \eta_{mov}$; $\eta_{fr}$ and $\eta_{mov}$ - efficiency of the transmission and propulsion engine, respectively; $\eta_i$ - indicative engine efficiency; $H_u$ - the net calorific value of the fuel; $\hat{A}_{\eta_m}$ - amplitude value of the input disturbance; $M_{en}^a = 0.15 M_{en}$; $M_{en}$ - rated effective torque; $\omega$ - angular velocity of rotation of the crankshaft; $m$ - the mass of MTU, $m = m_t + m_p$; $m_t$ - the tractor mass; $m_p$ - the plough mass; $\alpha$ - elevation angle of the track section; $f_{rf}, f_{pf}$ - the rolling friction coefficients of the propulsion engine and the sliding friction of the plough on the bottom and wall of the furrow, respectively; $k_f$ -
soil resistivity; \( a, b \) - tillage depth and plough width; \( \xi \) - dynamic coefficient; \( \tilde{\gamma}_{61}(j\omega) \) - transfer function of oil pressure in the main oil line (MOL); \( \tilde{\gamma}_{11}(j\omega) \) - transfer function of the crankshaft rotational speed of the MTU power-generating unit; \( \Theta^P_{\gamma}(j\omega) \) - the transfer function of the oscillations of the MTU frame in the longitudinal-vertical plane in ploughing mode; \( V_C \) - the working volume of one cylinder of the engine; \( i_\ell, \tau_\ell \) - the number of cylinders and type of power cycle, respectively; \( a_1\), \( b_1 \) - coefficients obtained experimentally for each type of engine; \( P_{\text{min}} \) - oil pressure in MOL at nominal rotation speed; \( \gamma = 10^{-3} \omega_\ell \omega_n \) - nominal angular velocity of rotation of the crankshaft.

The transfer function of the rotational speed of the crankshaft of the MTU power-generating unit with respect to the disturbing influence (at a fixed position of the organ \( h(i) \) that specifies the value of the cyclic fuel supply, \( b_0 = \text{const} \) [6, 7]:

\[
\tilde{U}_{11}(j\omega) = \frac{\tilde{\xi}_{11}(T_1^2 s^2 + 2T_2 \tilde{\xi}_1 s + 1)}{(T_1 s + 1)(T_2^2 s^2 + 2T_3 \tilde{\xi}_2 s + 1)(T_4 s + 1)},
\]

where \( k_{11} \) - the transmission speed ratio; \( T_1, T_2, T_3, T_4 \) - time constants; \( \tilde{\xi}_1, \tilde{\xi}_2 \) - attenuation coefficients.

For the engine SMD-20T.04: \( k_{e1} = 1.80; T_1 = 1.073 \text{ s}; T_2 = 0.531 \text{ s}; T_3 = 0.398 \text{ s}; T_4 = 0.354 \text{ s}; \tilde{\xi}_1 = 0.300; \tilde{\xi}_2 = 0.250 [6, 7].

Note that for MTU, taking into account its mass \( m \), the moment of inertia given to the \( I_a \) crankshaft and the time constant \( T_1 \) are

\[
I_a = I_\ell + \frac{m R^2}{l^2} ; \quad T_1 = \frac{\pi}{30} I_a \frac{n_n^2}{N_n},
\]

where \( I_\ell \) - the moment of inertia of the engine; \( N_n \) - nominal engine power.

The transfer function of the oscillations of the MTU core in the longitudinal-vertical plane in the ploughing mode is determined by the amplitude-phase frequency characteristics of the deformation of the suspension of the carriages per unit of disturbance of the track unevenness at \( s = j\omega \) [7,13]:

\[
|\Theta^P_{\gamma}(j\omega)| = k_0 |\omega|^2 \sqrt{\frac{\left[ \mu_0 m_1 m_2 \omega^2 \left( \frac{1}{\tau_{d1}} - 1 \right) + c_1 (m' + \frac{1}{\tau_{d1}} m^\prime) \right]^2}{\left[ \mu_0 m_1 m_2 \omega^4 - \omega^2 (m_1 c_1 + m_2 c_1 + \beta_1^2) + c_1^2 \right]^2}} \ldots + \omega^2 \beta_1^2 (m' - \frac{1}{\tau_{d1}} m^\prime)^2 + \ldots + \omega^2 (\beta_1 (c_1 - m_2 \omega^2) - \beta_1 (c_1 - m_2 \omega^2))^2,
\]

where \( k_0 = \cos(2\pi l_k / l_i) \approx 0.7; l_k \) - the distance between the axes of the carriages; \( l_i \) - the length of the micro-relief of the arable land; \( c_1 \) - stiffness of the support suspension, \( c_1 = 1400 \text{ kN/m}; \omega \) - frequency of repetition of roughness, \( \omega = 2\pi v / l_i \); \( v \) - MTU speed; \( \beta_1 \) - damping parameter,

\[
\beta_1 = 2v_n \sqrt{\frac{m}{m_n}} ; \quad v_n = 0.3; \quad \mu_0 = 1 - \frac{m_0}{m_1 + m_2} = 0.66; \quad m_0 = \frac{l_s - m_1 \ell_1 / 2}{l_2^2} = 5544.5 \text{ kg}; \quad m_1 = \frac{l_s + m_1 \ell_1 / 2}{l_2^2}
\]
= 9599.2 kg; \( m_2 = \frac{I_s + m_{fa}}{l^2} \) = 7003.7 kg; \( m_{tp} \) - tractor sprung weight, \( m_{tp} = 8400 \) kg; \( m_{fa} \) - tractor weight per axle of the front carriages \( m_{fa} = 4400 \) kg; \( m_{ra} \) - tractor weight per axle of the rear carriages \( m_{ra} = 4000 \) kg; \( l \) - wheelbase, \( l = l_1 + l_2 = 1.75 \) m; \( l_1 = 0.31 \) m; \( l_2 = 1.44 \) m; \( I_s \) - moment of inertia of the system, \( I_s \approx m_{tp} l_2^2 \), \( I_s = 23936 \) kg \( \cdot m^2 \); \( m' = m_0 + m_1 \); \( m'' = m_0 + m_2 \); \( \tau = l/v \); \( \lambda_d \) - the dominant lower natural frequency of the tractor frame.

The transfer function of oil pressure in the MOL of the engine:

\[
|G_{61}(j\omega)| = k_{m1}U_{11}(j\omega),
\]

where \( k_{m1} \) - the transfer rate of oil pressure in MOL; \( k_{m1} = 1.20 \).

Entering the values of \( U_{11}(j\omega) \) from (3), \( \Theta_P(j\omega) \) from (5), \( |G_{61}(j\omega)| \) from (6) into (2), we determine the surface of the state of frequency characteristics (FC) of the hourly fuel consumption of the MTU diesel engine in ploughing mode (figure 1). The numerical values of the hourly fuel consumption are determined by entering the following source data into (1) and (2):

- \( v_c = 1.575 \) l; \( i_c = 4 \);
- \( \tau_e = 2 \); \( \alpha = 0.45 \); \( b_1 = 0.97 \cdot 10^{-3} \); \( \eta_1 = 0.40 \);
- \( H_M = 41300 \) kJ/kg; \( P_{min} = 0.6 \) MPa; \( n_n = 1900 \) min\(^{-1} \);
- \( N_{en} = 88 \) kWt; \( I_e = 2.40 \) kg \( \cdot m^2 \); \( M_{en} = 480 \) N\( \cdot m \);
- \( \gamma = 0.188\) s\(^{-1} \); \( F_e^d = 0.15 \) \( M_{en} \);
- \( \eta_m = 0.68 \);
- \( R = 0.238 \) m; \( m_t = 10400 \) kg; \( m_{pl} = 520 \) kg; \( \alpha = 0.15 \) m; \( h = 0.70 \) m [7].

When ploughing light soils, the following conditions of MTU functioning are adopted:

- \( f_{pf} = 0.15 \);
- \( f_{pf} = 0.40 \);
- \( k_f = 5 \cdot 10^4 \) N/m; \( \zeta = 1600 \) kg/m\(^3 \);
- \( \delta_s = 0.03 \);
- \( q_k = 2 \cdot 10^6 \) N/m\(^2\);
- \( z_0 = 0.06 \) m; \( \alpha = 5^\circ \).

Figure 1. The surface of the state of FC of the hourly fuel consumption of an MTU diesel engine mounted on an LHT-100 tractor with a PKL-70 plough in ploughing mode, depending on the speed of movement, with a standard suspension rigidity \( c_1 = 1400 \) kN/m.

Making sections in a longitudinal-vertical plane (Figure 2) for any fixed value of the regular speed \( \omega_0 \) of movement of MTU and over the entire range of frequencies \( \omega \) of oscillations of the load on
the leading sprockets, we can calculate the regular component $A^0 P$ and the dynamic component of the hourly fuel consumption $A P(\omega)$.

Figure 2. FC of the hourly fuel consumption by components when ploughing light soil by MTU based on an LHT-100 tractor with a PKL-70 plough with a suspension stiffness $c_1 = 1400$ kN/m: a - at a driving speed $\nu_0 = 0.86$ m/s; b - at a speed of movement $\nu_0 = 1.15$ m/s; 1 - resistance to the movement of MTU on the rise; 2 - cutting and turning over; 3 - MTU inertial forces; 4 - tractor oscillations in the longitudinal-vertical plane; 5 - mechanical losses in engine friction pairs; 6 - total consumption for dynamic loads.

2.2. Analysis of the hourly fuel consumption components of an MTU diesel engine in a ploughing mode

The criterion function (2) allows calculating the hourly fuel loss for each dynamic component in the frequency spectrum $0 \ldots 20$ s$^{-1}$ (figure 2), as well as the value of the dynamic component for different values of $c_1 = 1800, 1400, 1000$ kN/m:

1 - from the resistance when moving uphill with a plough

$$A^1 P(\omega) = \frac{4A_1 R \cdot L}{\eta_1 \eta_{m\phi} \eta_e} \cdot \int_{\omega=0}^{\omega=20} \omega \Phi_{11}(j\omega) \left[ A_1^1 P + A_2 + 3A_3 \right] \left| U_{11}^2(j\omega) \right| d\omega;$$  

(7)

2 - from the dynamics of the resistance of a plough (cutting and turning over)

$$A^2 P(\omega) = \frac{4A_1 R \cdot L}{\eta_1 \eta_{m\phi} \eta_e} \cdot \int_{\omega=0}^{\omega=20} \omega \Phi_{11}(j\omega) \left[ A_2 + 3A_3 \right] \left| U_{11}^2(j\omega) \right| d\omega;$$  

(8)

3 - from oscillations of the MTU suspension in the longitudinal-vertical plane

$$A^3 P(\omega) = \frac{4A_1 R \cdot f_{tf} \cdot L}{\eta_1 \eta_{m\phi} \eta_e} \cdot \int_{\omega=0}^{\omega=20} \omega \Phi_{11}(j\omega) \left| \Phi_{11}^P(j\omega) \right| d\omega;$$  

(9)

4 - from MTU inertial forces

$$A^4 P(\omega) = \frac{4A_1 R \cdot L}{\eta_1 \eta_{m\phi} \eta_e} \cdot \int_{\omega=0}^{\omega=20} \omega^2 \left| U_{11}^2(j\omega) \right| d\omega;$$  

(10)

5 - from mechanical losses in the engine friction pairs
Total fuel losses per hour for dynamic loads in the frequency spectrum 0 ... 20 s\(^{-1}\) at various values of \(c_1\) = 1800; 1400; 1000 kN/m

\[
B^P_0(\omega) = \frac{E_1D_1M^a_s}{\omega_e} \cdot \int_{\omega=0}^{\omega=20} \left| \frac{a_i}{P_{max}} \cdot \left[ \frac{4\omega^2 + \gamma^2}{\omega^2 + \gamma^2} \cdot |G_{i1}(j\omega)| \right] + 2b_i\omega \cdot |U_{i1}(j\omega)| \right| d\omega;
\]

where \(\omega_e\) - own lowest frequency of oscillations of MTU; \(G_{31}^P(j\omega)\) transfer function of the hourly fuel consumption in ploughing mode [7].

The actual hourly fuel consumption \(\hat{A}^P_1\) in ploughing mode, taking into account the losses on dynamic loads, for different values of \(c_1\) = 1800; 1400; 1000 kN/m were determined by the sum

\[
\hat{A}^P_1 = \hat{A}^P_{10} + \hat{A}^P(\omega)
\]

The results of calculations (7) - (13) in the operation of MTU in ploughing mode are summarized in table 1.

**Table 1.** The results of the calculation of the hourly fuel consumption of MTU based on the tractor LHT-100 with a plough PKL-70 in the mode of ploughing light soils.

| Speed of MTU movement \(v_0\), m/s | Regular component \(B^P_0\), kg/h | Total dynamic components \(B^P(\omega)\), kg/h at different values of rigidity \(c_1\), kN/m | Elements of the dynamic component \(B^P_i(\omega)\), kg/h at rigidity \(c_1 = 1400\), kN/m |
|----------------------------------|---------|---------------------------------|-----------------------|
| \(0.86^a\)                      | 10.507  | 1.133                           | 1.140                 |
|                                 |         | 1.138                           | 0.598                 |
|                                 |         |                                 | 0.327                 |
|                                 |         |                                 | 0.023                 |
|                                 |         |                                 | 0.142                 |
|                                 |         |                                 | 0.050                 |
| \(1.15^b\)                      | 14.086  | 1.402                           | 1.411                 |
|                                 |         | 1.408                           | 0.748                 |
|                                 |         |                                 | 0.409                 |
|                                 |         |                                 | 0.022                 |
|                                 |         |                                 | 0.180                 |
|                                 |         |                                 | 0.052                 |

\(^a\) \(\omega_e = 2.23\) s\(^{-1}\) - II transmission (\(i_t = 44.226\));

\(^b\) \(\omega_e = 2.51\) s\(^{-1}\) - III gear (\(i_t = 32.854\));

\(^c\) Components: 1 - resistance to the uphill movement of MTU; 2 - cutting and turning over; 3 - MTU inertial forces; 4 - tractor oscillations in the longitudinal-vertical plane; 5 - mechanical losses in the engine friction pairs.

**3. Results and Discussion**

When ploughing light soils, the frequency response of the hourly MTU fuel consumption for dynamic loads is realized with one extremum (Figure 2b, curve 6). The greatest fuel consumption, 3.416 kg/h, occurs at the natural frequency of the engine crankshaft \(\omega_e = 2.5\) s\(^{-1}\). Of the dynamic components, the resistance to the uphill movement of MTU and cutting and turning over by the plough have the greatest values of fuel consumption (Figure 2, curves 1, 2).
The speed of movement $v_0$ has a significant impact on the regular component of fuel consumption per hour $p_0^B$, as well as on the dynamic components $b_1^P(\omega)$ (Table 1), therefore the choice of the transmission ratio of the transmission and gearbox at the design stage should provide effective traction and speed modes of MTU.

The plough recessed position in the ploughing mode limits the movement of the tractor's rear carriage and the amplitude of oscillations in the longitudinal-vertical plane, therefore varying the rigidity of the suspension does not significantly affect the total dynamic components $b_1(\omega)$ of the hourly fuel consumption.

To improve the fuel efficiency of MTU diesel engines, the design of which includes the fuel pump rail (FPR), it is necessary to use a correction device.

As a corrective device, it is advisable to use a FPR oscillation damper [6, 7, 9]. The vibration damper is used to reduce the amplitude of oscillations of the rail and the negative effect of the hydrodynamic force on the quality of the speed control process. Its advantage is that, while damping, it reduces the effect of hydrodynamic force during fuel cut-off and, to a lesser extent, resists when moving RFP in the direction of increasing the cycle fuel supply.

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References
[1] Lurie A B 1970 Statistical dynamics of agricultural aggregates (Leningrad: Kolos) 376 p
[2] Lurie A B 1967 Automation of agricultural aggregates (Leningrad: Kolos) 264 p
[3] Goryachkin V P 1968 Collected Works vol 1 (Moscow: Kolos) 720 p
[4] Barsky I B, Anilovich V Ya and Kutkov G M 1973 Tractor dynamics (M.: Mashinostroenie) p 280
[5] Kutkov G M 2004 Tractors and cars. Theory and technological properties (Moscow: Kolos) p 504
[6] Antipin V P 2012 Power consumption of a machine-tractor unit (Saint-Petersburg: Publishing House of The Polytechnic University) p 324
[7] Antipin V P 2017 Productivity, energy consumption and resource of the machine-tractor unit (Saint-Petersburg: Publishing House of The Polytechnic University) p 484
[8] Antipin V P, Durmanov M Y and Mikhailov O A 2019 Choosing Transmission Gear for Agricultural Aggregates Based on Energy Consumption Proceedings of the 4th International Conference on Industrial Engineering, ICIE 2018 ed Radionov A, Kravchenko O, Guzeev V and Rozhdestvenskiy Y (Springer, Cham) pp 1591–1600
[9] Durmanov M Y, Martynov B G and Spiridonov S V 2019 Energy and Fuel Consumption of Agricultural Aggregate Proceedings of the 4th International Conference on Industrial Engineering, ICIE 2018 ed A Radionov, O Kravchenko, V Guzeev and Y Rozhdestvenskiy (Springer, Cham) pp 1601–1612
[10] Vlasov E N, Mikhailov O A, Durmanov M Ya and Epifanova A Yu 2015 Estimating the amount of energy spent on the implementation of the tangential power of the tractor LHT-100 in ploughing mode News of St. Petersburg Forest Technical Academy Issue 212 (Saint-Petersburg: SPbGTU) pp 104–112
[11] Vlasov E N, Mikhailov O A, Durmanov M Ya and Epifanova A Yu 2015 Estimating the amount of energy spent on the implementation of the tangential power of the tractor LHT-100 in transport mode News of St. Petersburg Forest Technical Academy Issue 213 (Saint-Petersburg: SPbGTU) pp 138–147.
[12] Spiridonov S V, Durmanov M Ya and Mikhailov O A 2017 Energy costs for the implementation of the tangential force of the forestry MTU in the transport mode 2nd International Scientific and Technical Conference “Forests of Russia: politics, industry, science, education” (Saint-Petersburg: SPbGTU) Vol 3 pp 43–46

[13] Durmanov M Ya, Mikhailov O A and Spiridonov S V 2017 Assessment of the dynamic load of a power transmission of a machine-tractor unit at the design stage Proceedings of the scientific and technical conference of the Institute of technological machines and forest transport following the results of research activities in 2017 ed V A Sokolova (Saint-Petersburg: SPbGTU) pp 174–183

[14] Durmanov M Ya, Spiridonov S V and Mikhailov O A 2018 Estimated hourly fuel consumption of a forestry machine-tractor unit at the design stage 3rd International Scientific and Technical Conference “Forests of Russia: politics, industry, science, education” (Saint-Petersburg: SPbGTU) Vol 2 pp 164–167

[15] Martynov B G, Durmanov M Ya and Mikhailov O A 2018 Estimation of the capacity of a forestry machine-tractor unit in ploughing mode 3rd International Scientific and Technical Conference “Forests of Russia: politics, industry, science, education” (Saint-Petersburg: SPbGTU) Vol 2 pp 191–195

[16] Durmanov M Ya, Martynov B G, Spiridonov S V and Mikhailov O A 2018 Assessment of the dynamic loading of the power transmission of the forestry machine-tractor unit Status and prospects of development of the forest complex in the CIS countries: Proceedings of the International Scientific and Technical Conference (Minsk: BSTU) pp 8–12