THE STUDY OF OPERATIONAL PARAMETERS OF A WHEELED TRACTOR WITH A GAS ENGINE IN THE TRANSPORT PROCESS
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ДОСЛІДЖЕННЯ ЕКСПЛУАТАЦІЙНИХ ПОКАЗНИКІВ КОЛІСНОГО ТРАКТОРА З ГАЗОВИМ ДВИГУНОМ У ТРАНСПОРТНОМУ ПРОЦЕСІ

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ABSTRACT
Here are the results of the theoretical studies of the indications of a wheeled tractor with a gas engine in the appropriate modes of the transport process. The rational values of the parameters of the transmission and the gas engine control during the tractor acceleration and the values of the speeds of a steady movement in operating conditions according to the criteria of the minimum specific fuel consumptions and harmful emissions were selected and justified on the basis of calculations on the mathematical model of a wheeled tractor movement on a specially formed driving cycle. It was found that the maximum engine rotation is in the range of 1400…1500 min^{-1}, the size of opening of the throttle valves is in the range of 50…60 % when the speed of opening of the throttle valves to 75 %/s is optimal. Using these recommendations it is possible to achieve fuel saving up to 10 % and significantly to reduce emissions of harmful substances together with exhaust gases.

РЕЗЮМЕ
Наведено результати теоретичних досліджень показників колісного трактора з газовим двигуном у характерних режимах транспортного процесу. На підставі розрахунків математичної моделі руху колісного трактора за спеціально сформованим їздовим циклом обрані й обґрунтовані раціональні значення параметрів керування трансмісією і газовим двигуном під час розгону трактора і швидкостей усталеного руху в експлуатаційних умовах за критеріями мінімальних питомих витрат палива і шкідливих викидів. Встановлено. що оптимальними є частота обертання колінчастого вала в діапазоні 1400…1500 хв$^{-1}$. відкриття дросельних заслінок газоповітряного змішувача 50…60 % при швидкості їх відкриття до 75 %/с. Використовуючи дані рекомендації можна досягти економії палива до 10 % і істотного зниження викидів шкідливих речовин з відпрацьованими газами.

INTRODUCTION
Everyone knows that agricultural machines are equipped with diesel engines of a good fuel efficiency and are unpretentious in operation and in maintenance. However, the increasing demands of environmental characteristics of vehicles including agricultural ones require the improvement of their structure, which will provide a significant reduction of emissions of harmful substances together with exhaust gases. This is because a lot of wheeled tractors in agricultural production are constantly used as technological transport for maintenance of livestock farms, greenhouses, warehouses, etc. Along with this they go inside and work for a long time indoors that causes harm to the health of people and of other biological objects. After a few minutes of engine running in an enclosed space the maximum allowable concentration of emissions of harmful substances exceeds the permissible limits (Zaharchuk V.I.. 2011).

The previous scientific researches (Mateichyk V.P.. 2008; Zaharchuk V.I.. 2011) showed that one of the effective ways of improving the environmental performance of tractors with diesel engines is their conversion to running on compressed natural gas (CNG), including the ability to run on biomethane which is a product of agricultural production.

Today the leading scientific research and engine-building organizations and companies are engaged in conversion and upgrading of diesel engines to their running on CNG. They are MAN, Scania, Nissan, Mercedes-Benz, CUMMINS, Iveco, Moscow automobile and road Institute, all-Russian scientific-research Institute of gas, Scientific automobile engine Institute, Kharkiv national automobile and road University, The Institute of problems in machine engineering and others (Nylund N.. 2002).

Our research has found that, according to 13 modes ETS cycle the total toxicity of exhaust gases reduced to carbon oxide CO is 1.83 times less than that of diesel (Mateichyk V.P.. 2008).

The analysis of work modes of the wheeled tractors engines in operational conditions has shown that about 40 – 45 % of all works performed by tractors are the transport works. When doing them the engines run primarily in transient modes in which the parameters of transmission and engine control have a substantial impact on fuel efficiency and on environmental performance of machines.

The analysis of the results of studies of vehicles with diesel engines converted to CNG ones has shown that no one has done the research of influence of transmission and gas engine control parameters on the operational performance of such vehicles in the transport process.

Therefore, the actual scientific-technical problem is to study the influence of parameters of control of the tractor transmission and of the gas engine converted from diesel one on the performance of the tractor running in operational modes.

The aim of this work is to study the regularity of changes in fuel consumption and harmful emissions of a wheeled tractor with the gas engine depending on the parameters of a transmission and a gas engine control during their transportation work and the argumentation of the choice of rational values of these parameters.

MATERIAL AND METHOD

The choice of rational parameters of the transmission and the gas engine control during tractor acceleration and the selection of appropriate speeds of the steady movement were carried out by simulation on a mathematical model of movement of a tractor with a trailer in the adopted "acceleration–movement with steady speed–deceleration" driving cycle. This simulation corresponds to the tractor operating conditions in the transport process and describes the modes of movement (Mateichyk V.P.. 2010).

The mathematical model is represented by a number of differential and algebraic equations describing the patterns of change in the tractor speed, fuel consumption and emissions of harmful substances in exhaust gases at each elementary field of the driving cycle. The input parameters of the mathematical model are the size of opening φ_{thr} and the speed V_{thr} of opening of throttle valves of gas and air mixer, the gear ratio U_i of the gearbox and the engine rotation frequency n_{ef} . at which the operator turns higher gear during acceleration. φ_{thr}. V_{thr}. and n_{ef} set by the operator, define the vacuum in the intake pipe. The vacuum in the intake pipe and the rotation frequency determine the engine operating modes, the hourly gas G_{gas} and air G_a consumption, the content of carbon oxides *CO.* hydrocarbons C_mH_n and nitrogen oxides NO_x in the exhaust gases.

The base engine parameter is a torque moment M_t. the value of which at the throttle valves position given by operator is determined by such conditions at the output: by characteristics of the road (its longitudinal slope i. the coefficient of resistance to rolling of a tractor and a trailer wheels f_0); by own weight of the tractor M_0; by the mass of the load M_l ; by the gear U_i the operator selected; and by the factor of air resistance kF. This is because these conditions determine the speed of the tractor and, correspondingly the frequency of rotation of the engine crankshaft.

In the mathematical model we simulate the movement of a wheeled tractor with a trailer on the road. In every moment of the cycle we determine its engine running modes (rotation frequency and vacuuming behind the throttle valves of gas and air mixer) on the basis of which we calculate fuel consumption, harmful emissions, traction-speed characteristics of a tractor at the elementary section of the path, generally in the mode and for the entire cycle of the tractor movement. This is according to experimentally defined characteristics considering the features of engine running in transient modes.

A refined mathematical model of movement of the gas engine tractor on driving cycle simulating the transport process allows to study the influence of transmission and a gas engine control parameters on the economic and environmental performance and to choose appropriate speed of the steady movement (Zaharchuk V.I.. 2015).

The checking of the adequacy of the mathematical model of a tractor movement was carried out by comparing the estimated speeds with the data of experimental studies obtained with the implementation of driving cycle on a tractor and with the comparisons of fuel consumptions (Mateichyk V.P.. 2012).

RESULTS

Theoretical studies (Zaharchuk O.V.. 2012) of the performance of the tractor with a gas engine were carried out according to the algorithm of determining of the rational values of the transmission and gas engine control parameters. It is shown in Fig. 1.

The algorithm allows to determine: 1) the appropriate order of gear-shifting in dependence on the operating conditions by the criterion of minimum specific fuel consumption; 2) the rational maximum engine rotation frequency at which gear-shifting goes on; 3) the rational values of the size and the speed of opening of the throttle valves during acceleration according to the criterion of minimum total emissions of harmful substances. It also allows to set proper speeds of the steady movement of the tractor, depending on the rolling resistance coefficient.

The first stage of the study was to determine an appropriate order of gear-shifting during acceleration of the tractor. Along with this the maximum values of the gas engine control parameters were accepted. At this stage, the choice of the order of gear-shifting was carried out according to the criterion of minimum specific consumption of gas g_{gas}. On the mathematical model we simulated the acceleration of the tractor with different variants of gear-shifting and chose such order which showed the least gas consumption per 1 km of accelerating.

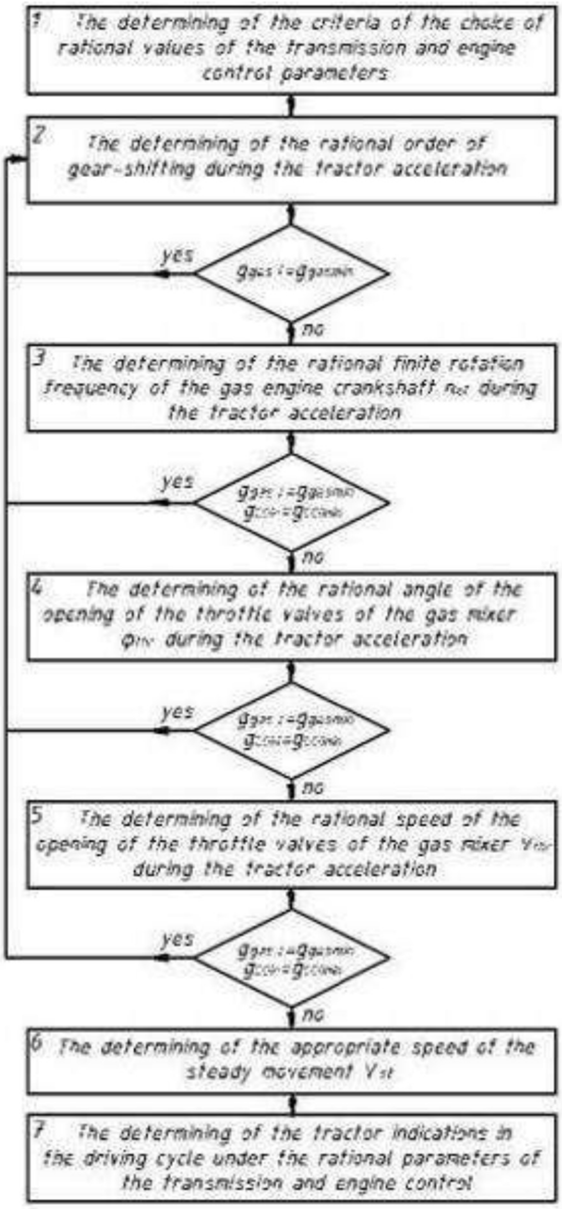

Fig. 1 - The algorithm of the determination of the expedient values of the parameters of the wheeled tractor transmission and gas engine control

The acceleration of the tractor when one chooses a proper gear-shifting was simulated with a coefficient of resistance to rolling wheels f_0 = 0.016, typical for dry asphalt-concrete and cement-concrete roads in a good condition. It was also simulated with a coefficient f_0 = 0.03. typical for dry dirt road and with the 4000 kg weight of the load.

The minimum specific fuel consumption occurs when shifting of gears is in the 6-8-9 order at f_0 = 0.016 and in the 6-7-8 order at f_0 = 0.03.

The next stage of the study was to determine rational parameters of the gas engine control. These parameters are: the rotation frequency of the engine crankshaft n_{ef} at the moment of gear-shifting, the throttle valves position φ_{thr} in each gear and the speed of opening the throttle valves of the gas and air mixer V_{thr}. taking into account the rational control parameters defined in previous stages of the research. The choice of control parameters was carried out according to the criterion of minimum specific gas consumption g_{gas} and of minimum total specific emissions of harmful substances reduced to carbon oxide $g_{\Sigma CO}$. During this choice the appropriate order of gear-shifting and the stepwise accounting of the rational values of gas engine control were taken into consideration.

With the use of the mathematical model the proper order of gear-shifting during acceleration of the gas engine tractor was determined.

Using the recommendations related to the appropriate gear-shifting order it is possible to achieve 3.9...9.8 % reduction of fuel consumption and a significant reduction of emissions of harmful substances together with exhaust gases.

The rational values of the parameters of the gas engine control during tractor acceleration were determined. In order to achieve the minimum specific emissions of harmful substances it is recommended to provide the maximum engine rotation frequency at which the gear shifting is in the range of 1400...1500 min^{-1}. and the size of opening of the throttle valves in the range of 50...60 % (Fig. 2) when the speed of opening of the throttle valves does not exceed 75 %/s.

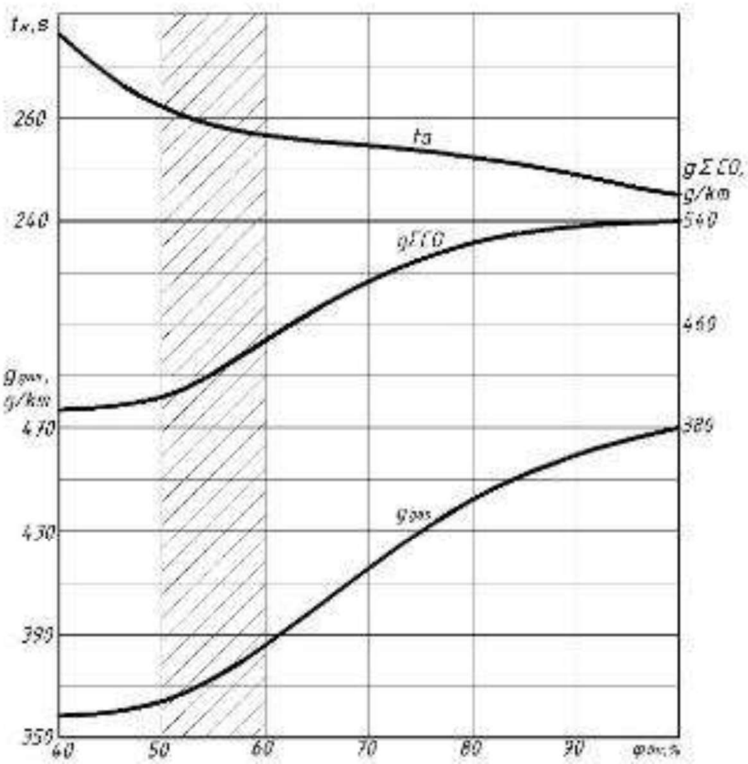

Fig. 2 - Dependences of the indications of the tractor from the angle of opening of the throttle valves

The last stage of the study was to establish the appropriate speeds of the steady movement at the corresponding segments of the driving cycle depending on the value of the coefficient of resistance to the wheels rolling taking into account the rational values of the parameters of the transmission and the gas engine control.

The proper speeds of the steady movement of the gas engine tractor in the driving cycle are installed depending on the coefficient of resistance to the wheels rolling. In particular, it is shown that achieving of minimum specific fuel consumption and minimal emissions of harmful substances on the road with the dry asphalt-concrete pavement is possible by performing driving cycle with the constant speed of 20...24 km/h and on the dry dirt road with the constant speed of 10...13 km/h (Fig. 3).

CONCLUSIONS

Using the mathematical model of the wheeled tractor movement in the transport process we determined the rational values of the parameters of the transmission and the gas engine control in the acceleration modes and the appropriate speeds of the steady movement of the tractor according to the criteria of the minimum specific fuel consumption and harmful emissions together with exhaust gases.

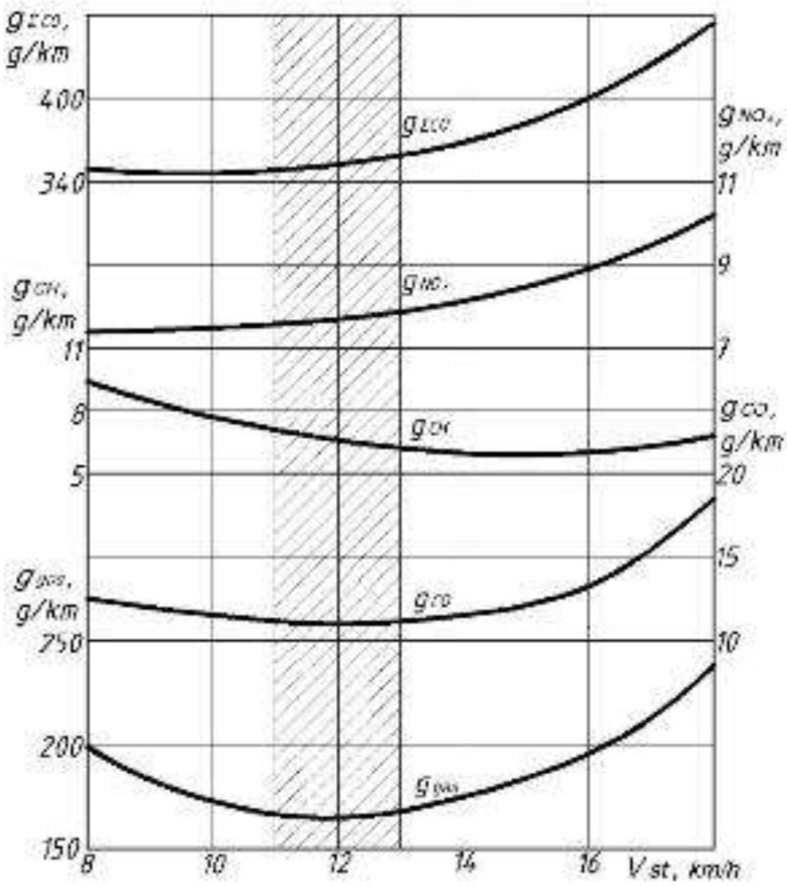

Fig. 3 - Dependences of gas consumption and harmful emissions on the speed of the tractor steady movement. when the coefficient of the resistance to rolling is f_0 = 0.03

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