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Engine performance during tractor operational period

Algirdas Janulevičius *, Antanas Juostas [1], Gediminas Pupinis [1]

Department of Power and Transport Machinery Engineering, Aleksandras Stulginskis University, Studentų str. 15, 53361 Kaunas-Akademija, Lithuania

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ABSTRACT

It was found that for monitoring operating performance of the tractors it is necessary to have tools and methods that, by using data provided by the manufacturer and controlled during tractor's operational time, would allow to directly determine fuel consumption, exhaust emissions, engine load modes and other indicators. Such problems are dealt with in this article. Possibilities for using data accumulated in database of tractors' engine control processors to explore engine load, fuel consumption and exhaust emissions are analyzed.

This paper presents the results of engine load, fuel consumption and exhaust emissions' research for tractor models Massey Ferguson MF 6499 with different operational time records within their operational period. The research results show how much time during the operational period, averagely, tractor engines worked by producing the torque 30%, 30–50% and >50% and the potential maximum torque in that mode. It is also presented how long engines operated at each load at slow speed (up to 1100 rpm), medium speed (from 1100 to 1900 rpm) and high speed (more than 1900 rpm). The paper presents average fuel consumption and CO, CO_2 and NO_x emissions by the engines for every of these operation modes during operational period of the tractors.

1. Introduction

During last century the worldwide energy consumption showed more than 20-fold increase and is expected to continue its growth in future. One of the biggest problems of the 21st century is linked with eventual depletion of fossil fuels, growing ambient air pollution and global warming occurring because of the increased CO_2 (carbon dioxide) emissions [1,2]. Fuel consumption increases because of the growing number of diesel engine powered heavy-duty haulage trucks, agricultural tractors and self-propelled machines as well as personal light duty cars.

Tractors are the main power machines in agriculture. In agriculture, tractors are subject to various farm operations. It begins with the spring work, such as soil tillage, seeding, fertilizing and spraying. Later, feed preparation, mowing, compaction, transport works. And in autumn, soil plowing, cultivating, autumn seeding, etc. Today's conditions of production and environmental requirements force equipment users to reduce fuel consumption and toxicity of exhaust [3,4]. Environmental advantages that would be essentially important for reducing air pollution caused by transport and agricultural sectors in order the amount of the exhaust gases should comply with the stringent EU emission standards. Despite global progress in reducing fuel consumption by new tractors and vehicles, the production of machines is increasing and total economy of the fuel still lacks behind. In spite of high market prices, demand of fuels, especially diesel fuel, increases faster than their production capabilities. Moreover, as the demand for energy has grown, so have the adverse environmental effects of its production with CO_2, CO (carbon monoxide), NO_x (nitrogen oxides), SO_x (*sulfur* oxides) emissions originating from fuel combustion being primary sources of atmospheric pollution [5–7].

The flawless, economical, and ecological operation is required from tractor's engines and their equipment. The best ecological and economical tractor operation results are not reached only by technical development. Complex measures are required to improve technical characteristics of tractors and other machinery, also their performance in the production process [8,9]. Fuel consumption and emissions depend on the engine speed and load characteristics. In order to use the tractors effectively, they must be adopted to intended works in the best possible way. When composing tractor and machine units, the focus should be to the tractor working at optimum load conditions. By working with agricultural equipment in a skilled way, it is possible to save fuel and reduce exhaust emissions [10,11]. But this requires knowledge of the operation subtleties and ability to assess the interaction between tractor's systems and mechanisms. During their whole lifecycle most of the tractors are running at 50–70% of max. load [10,12–14]. Many researchers suggest that at these periods (when operating at partial load) the tractors should be operated at reduced engine speed. When

* Corresponding author. Tel.: +370 37 752285.
E-mail addresses: algirdas.janulevicius@asu.lt (A. Janulevičius), antanas.juostas@kesko.lt (A. Juostas), gediminas.pupinis@asu.lt (G. Pupinis).
[1] Tel.: +370 37 752285.

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Nomenclature

A_m	work for operating mode, kJ
B_d	hourly fuel consumption, kg h^{-1}
B_m	fuel consumption at particular mode, kg
b_c	cyclic fuel injection quantity, mg
b_{cm}	cyclic fuel injection quantity at particular mode, mg
b_e	specific fuel consumption, g kW^{-1} h^{-1}
b_{em}	specific fuel consumption for operating mode, g kW^{-1} h^{-1}
$E_{(e)}$	emission of engine exhaust gas component (e, i.e., CO_2, CO or NO_x), g kW^{-1} h^{-1}
$E_{(x)}$	emission of engine exhaust gas component, during the work (x, i.e., CO_2, CO or NO_x), g
$E_{(x,PPM)}$	emission of engine operating mode component (i.e., CO_2, CO or NO_x), ppm
i_c	number of the engine cylinders
K_m	engine load factor for operating mode (according to power)
M	engine torque, N m
M_m	engine torque for operating mode, N m
$M_{\max}$	engine maximum torque, N m
n	engine speed, min^{-1}
n_m	engine speed at particular mode, min^{-1}
P	engine power, kW
P_m	engine power for operating mode, kW
$P_{\max}$	engine maximum power, kW
t	engine operational time, s
t_m	engine operational time at particular mode, s
ε	factor for assessing changes in engine load at operating mode
σ_E	gas flow, m^3 h^{-1}
σ_O	supply air flow, m^3 h^{-1}
ρ_E	gas density, kg kmol^{-1}
η_{σ_O}	factor of supply air flow volumetric efficiency
υ_e	engine capacity, cm^{-3}
CO	carbon monoxide (engine exhaust gas component)
CO_2	carbon dioxide (engine exhaust gas component)
NO_x	nitrogen oxides (engine exhaust gas components)
HC	hydrocarbons (engine exhaust gas components)
PM	particulate matter (engine exhaust gas components)
SO_x	*sulfur* oxides (engine exhaust gas components)

maximum power of engine is needed, they recommend the mode of constant engine power. They recommend loading the engine so that it operates at the average speed. For most tractors, minimum fuel consumption is obtained by working at 80% of rated power and 80% of rated speed [14,15]. It is important to choose the implements correctly according to the tractor's power and operations to be completed. The results showed that implements with large working width increase productivity by making minor changes in fuel consumption, but CO and NO_x emissions are increased at the same time [16]. Currently, users have a tendency to buy smaller, but more powerful tractors. This tendency leads to the use of smaller implements, but having in mind tractor's power, fuel consumption and exhaust emissions increase [10,16,17].

Diesel fuel consumption depends on engine speed. If the engine runs at high speed, friction and heat losses are higher. When engine temperature rises, cooling fan consumes more power. When engine's cooling system is operating at full capacity, up to 10% of engine power is lost. In addition, the rise in engine temperature increases NO_x emissions [18,19].

There is no technology to eliminate CO_2 emissions for working internal combustion engines. One simple and effective way to reduce CO_2 emissions is to avoid the tractor or vehicle operating at partial load and at idle [17]. This is an action that may be taken by the driver. By running at idle for 10 s, engine consumes more fuel and produces more CO_2, compared to the restarting of engine [17,18]. It is not recommended to reduce the headlands in order to save. If headlands are narrow, not only more time is wasted and more fuel is consumed, but changes in operating modes of tractor and engine are increased, also exhaust emissions are increased [8,15,20].

Analysis shows that in most of the farms tractor units, technological work diagrams and headland sizes are chosen without a based methodology and optimal mode of the tractor is overlooked. Often tractors work only partially loaded, i.e. only part of the tractor's power and traction force is utilized [10,20–22]. In addition, tractors and their engines work idle for considerable period during their operational time. If engine is idling for a long time, fuel is unnecessarily wasted and the environment is polluted [17,21,23]. Not many information exists about exhaust emissions of tractors during their operational time and how long they work efficiently. Specialists of agriculture and especially environmental specialists are not getting enough information about how tractors are polluting environment during their operation. They do not know how many pollutants are emitted by tractors into the environment while working for an hour, a day or a month. What kind of tractor and agricultural management techniques can be used with less pollution? Which tractor has polluted the environment more and why? Monitoring of tractor performance indicators still is an unsolved problem that needs to be addressed immediately.

The change of technical condition of combustion engine at any working point of engine proves different change of fuel consumption and production of harmful emissions [11,24–26]. It was found that for monitoring operating performance of the tractors it is necessary to have tools and methods that, by using data provided by the manufacturer and controlled during tractor's operational time, would allow to directly determine fuel consumption, exhaust emissions, engine load modes and other indicators [9,10,20,23,27].

Purpose of research – to create methodology of monitoring operating performance of the tractors for determining engine load, fuel consumption and exhaust emissions of the tractor and explore engine load, fuel consumption and exhaust emissions for the tractor operating in real work conditions during its operational time.

2. Objects, method and experimental apparatus of the research

For research of engine load, fuel consumption and exhaust emission characteristics during its operational time tractors "Massey Ferguson MF 6499" were chosen. Eight tractors from various-profile farms were chosen, which were utilized for plowing, tillage, sowing, transport and other activities. Tractors that were chosen had various operational time records; the shortest of these periods was 1317 h, and the longest – 5649 h. Average operational time record for these tractors was 2940 h. Every year these tractors worked from 800 to 1200 h. Tractor specifications: 4-stroke, 6-cylinder, liquid-cooled, 160.3 kW (at rated speed of 2200 rpm) diesel engine Sisu Diesel 74 CTA with a displacement 7.4 dm^3, cylinder bore 108 mm, piston stroke 134 mm, and compression ratio 17.5:1, engine maximum torque 950 Nm (1450 rpm), Common Rail fuel injection system, Tier 3 emission certification; transmission (Dyna-6): six power shift gears in four ranges; chassis: 4×4