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A model to assess tractor operational efficiency from bench test data

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Abstract

Agricultural mechanization is required to sustain food production with high productivity, but fuel resource limitation has spurred both tractor manufacturers and users to take care of their fuel consumptions. Fuel consumptions of tractors are often assessed from tractor oriented testing procedures which are assumed to reflect a variety of agricultural operations. However, the resulting diagnostic, based on an annual average use, lacks consistency and users are asking for a more detailed fuel assessment according to real use. A novel approach is therefore proposed here which aims to be more representative of real field usage and to better express the related energy performance. The approach is designed in order to be suitable with automotive applications estimating fuel needs over some so-called driving cycles. The driving cycle, also named field working dynamics, is investigated by monitoring an experimental tractor throughout a whole year of field operations. Statistical analysis is applied to discriminate and characterize different tasks during the tractor use in field operation: displacement, poor idling, maneuvering and driving along the field. Time and mechanical energy needs are described for each subtask. Then, a parametric model is used to convert mechanical needs into a fuel demand. It is designed to predict operational efficiency as a function of agricultural parameters. The model is calibrated for a tractor by laboratory test procedures. For validation purposes, the model was applied to a plowing operation, in which the predicted efficiencies for fuel, time and field are compared to the actual efficiencies measured in the field. Lastly, the effect of operational parameters on efficiency is discussed through a sensitivity analysis that links fuel consumption and productivity. This analysis shows the main parameters that have to be defined to characterize agricultural work and convert an engine diagnostic into a user-oriented consumption.

Keywords: Driving cycle; Efficiency indicators; Fuel consumption; Energy analysis; Testing procedure; Agricultural machinery

1. Introduction

Agricultural tractors are used throughout the year, with diverse implements to conduct different field operations. The engine and powertrain is therefore subjected to highly variable demands in terms of speed and load [1], thus making necessary for users, but difficult, the building of energy efficiency indicators by kind of use. Current standards used to assess off-road vehicle performance regarding fuel efficiency and pollutant emissions are respectively defined by the OECD [2] and the european directive procedures [3]. For these two engine testing procedures, the tractor is placed on a test bench and run under different operating conditions. OECD transmission tests are done over a test track, where the load is applied by a dynamometric truck. For each test type, the different running points are defined by a couple of engine speed and torque –respectively tractor speed and draft for the transmission tests. These points represent different field operations and reflect the actual usage in a way that has been the subject of many discussions summarized in the following paragraph.

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Nomenclature

Characters

α	draft angle (°)
L_{line}	field length (m)
B_n	mobility number (–)
MR	motion resistance (kN)
C	fuel consumption (L)
η	transmission efficiency (–)
C_T	total amount of fuel (L)
N	rotary speed (rpm)
D	duration (H)
P	power (kW)
d_{imp}	implement working depth
$[m]$	q_t transmission ratio (–)
F	traction force (kN)
ρ	motion resistance ratio (–)
FE	field efficiency (ha/h)
r	rolling radius (m)
GT	gross traction force (kN)
R_p	fan pulley ratio (–)
h	drawbar height (m)
s	slip (–)
I	marking signal ()
SF	field surface (ha)
I^*	autoscaled value of I $\left(I^* = \frac{I-\mu_I}{\sigma_I}\right)$
T	torque (Nm)
L	tractor wheelbase (m)
T_{ET}	total engine torque (Nm)
L_E	engine load (%)
V	tractor speed (km/h)
l_{imp}	implement width (m)
W	weight (N)

Subscripts and indices

$4WD$	4 wheel- drive shaft
$line$	working phase over line
b	ballast
m	measured
D	draft
man	working phase over maneuver
E	engine
o	operation
F	front
p	predicted
Fan	fan
R	rear
h	per hour
r	right
ha	per hectare
T	transmission
l	left
W	wheel

Statistics

$card$	number of elements
μ	mean value
G	class of data
n	number of paths
I	marker
σ	standard deviation

Initially designed for the control of power output, the OECD power-take-of test includes on 6 specific points at partial load, being each representative of one implement. The transmission test is designed for generally heavy and pure traction works. The emission test procedure defines both a nonroad steady cycle (NSCR) and a nonroad transient cycle (NRTC). The NRTC test is a transient driving cycle for mobile nonroad diesel engines developed by the US EPA and used internationally for emission certification of nonroad engines of the lastest stage (actual european stage III/IV regulation, the US EPA Tier 4 rule and Japanese 2011/13 regulation). The older NSCR is made of 8 steady running points also used in the ECE-R49 testing procedure. These points are defined and normalized by the nominal speed, nominal power and maximal torque and differ from those of the OECD procedure. General performance indicators about the fuel efficiency are derived from these tests by computing a weighted mean value of the specific consumption measured on each point. The weighting coefficients are currently chosen equal, conferring to each point a similar representativity of occurrences to cover a very wide tractor usage in [4,5]. Defining such an indicator makes the evaluation result very sensitive to the test point selection. Definition of the points has therefore been also widely debated: comparisons made between procedures using 5 or 8 points have shown considerable discrepancies of up to 15% in fuel efficiency [6]. The same problem occurs for emission measurements. Normalized procedures (ECE R49 type) lack representativity: comparisons with procedures fitted on real usage can show up to 40% of difference [7]. In comparison, procedures designed for on-road vehicles offer a better point distribution when suitable weightings are chosen [8]. Commonly used identical weightings do not reflect the reality of tractor field usages. High torque and high speed points are prone to be over represented, whereas low torque and low speed points are neglected. Choosing a test point which has a statistically limited signification and assigning it an incorrect weighting leads to bias, thus compromising the efficiency diagnostic up to now expressed in [g/kW h]. Bench tests can therefore give overestimated fuel consumption by using an high annual load coefficient [9].

Effective ways of determining tractor operation have been largely discussed on the basis of recordings made during field campaigns. Special instrumentation and monitoring devices have been installed to better understand field