Available online at www.sciencedirect.com

ScienceDirect

Journal of Terramechanics 65 (2016) 73–84

Journal of Terramechanics

www.elsevier.com/locate/jterra

Development of a dynamometric vehicle to assess the drawbar performance of high-powered agricultural tractors

M. Cutini *, C. Bisaglia

Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria – Unità di ricerca per l'ingegneria agraria (CREA-ING), via Milano 43, 24047 Treviglio (BG), Italy

Received 30 November 2015; accepted 27 March 2016
Available online 4 April 2016

Abstract

Agricultural tractors are machines originally designed to mechanize agricultural tasks, especially tillage and pulling. A large part of research activities have been interested in optimizing tractor efficiency, in particular in terms of emissions and energy. In this frame, the OECD Tractor Code 2 sets out a drawbar test in specific controlled conditions with the aim of evaluating the power of the tractor available at the drawbar. The principal measurement chain relies on dynamometric vehicles (DV) that are instrumented vehicles specifically engineered to develop horizontal force at the drawbar of agricultural tractors. The CREA Laboratory of Treviglio, Italy, engineered a new dynamometric vehicle to test tractors with up to 200 kW at the drawbar (245 kW at the engine flywheel) and a maximum of 118 kN drawbar force. The chosen basis is a FIAT 6605 N truck (TM 69 6 × 6) which has been transformed into a hydrostatic vehicle driven by a hydraulic system and an auxiliary gearbox. The maximum drawbar force was verified up to 122 kN. The drawbar power verification (200 kW) was successfully carried. The final verification confirmed that the project is valid for the investigation and optimization of the parameters regarding the traction efficiency of agricultural tractors.

Keywords: Drawbar power; Driveline; Tractor efficiency; Agricultural tyres

1. Introduction

Agricultural tractors are machines originally designed to mechanize agricultural tasks, especially tillage and pulling. During their technical evolution they have assumed a wide range of tasks as embracing the use of implements for agricultural land development, crop production, harvesting, storage and on-farm processing. Tractor testing has, consequently, followed technical developments and a wide range of methodologies, standards or manufacturers' proprietary protocols aim to cover all the parts needed to optimize traction performance. The studies were not only interested in the engine behaviour but also the driveline (Molari and Sedoni, 2008), tyres (Harris and Rethmel, 2011; Smerda and Cupera, 2010) and tractor settings (Janulevicius et al., 2014; Monteiro et al., 2013). Investigations were also carried out on the effect of different fuel types on traction and emissions (Da Cunha Siqueira et al., 2013). The main aims concerned the optimization of traction performance not only in terms of material engineering but above all labour and energy efficiency (Gil-Sierra et al., 2007; Turker et al., 2012; Grisso et al., 2004), also using models (Wong and Huang, 2006; Zoz and Grisso, 2003) verified by experiment results or bench-test data (Sabbioni et al., 2011; Lacour et al., 2014; Tiwari et al., 2010). Furthermore, in-depth investigations were conducted on the soil properties to determine their influence on traction efficiency and performance (Lyasko, 2010; Filho et al., 2010). An experimental drawbar test was required in order to continuously

* Corresponding author.
E-mail address: maurizio.cutini@crea.gov.it (M. Cutini).

http://dx.doi.org/10.1016/j.jterra.2016.03.005
0022-4898/© 2016 ISTVS. Published by Elsevier Ltd. All rights reserved.

Nomenclature

C_{max}	torque of hydraulic pump (Nm)	R_w	rotation speed of the vehicle's wheel (rad s^{-1})
c	pump capacity (cm^3 min^{-1})	R_p	rotation speed of the vehicle's pump (rad s^{-1})
F_d	drawbar force (N)	s	forward speed of the test tractor (ms^{-1})
Δp	pump pressure difference (bar)	T_a	ambient temperature (°C)
M_h	torque at the DV hub (Nm)	T_{oi}	oil coming out of oil valve temperature (°C)
M_p	torque at the pump (Nm)	T_{bp}	boiling point of coolant (°C)
P_{db}	power at the drawbar (W)	W_r	DV wheel radius (m)
P_d	power to dissipate (kW)	ATB	air to boil (°C)
P_{she}	specific heat exchange power (kW/°C)	DV	dynamometric vehicle
Q_o	oil flow (dm^3 min^{-1})	SSTC	steady-state thermal condition

investigate so many different factors affecting traction. This consisted of developing a horizontal force at the agricultural tractor drawbar while the tractor was running on a test track or in a field, and measuring the main vehicle outputs (i.e.: force, forward speed, wheel slip and fuel consumption). Besides, the requirement to measure drawbar force led to the development of specific sensors (Hvasi et al., 2012) and, in particular, a purpose-designed loading device able to generate a horizontal force at the drawbar of the tested tractor while it is moving forward. This mobile loading device is defined as a "dynamometric vehicle" (DV) or "dynamometer" as per the statement by the PAMI – Prairie Agricultural Machinery Institute (PAMI, 1996). Moreover, the dynamometric vehicle is fundamental for research centres involved in the international project promoted by the OECD for the standardization of agricultural and forestry tractor safety and testing.

Since 1959, the OECD Agricultural Codes and Schemes have been facilitating international trade by simplifying and harmonizing documentation, inspection and testing procedures.

The OECD Code 2 standard code for the official testing of agricultural and forestry tractor performance (OECD Code 2, 2015) sets out the drawbar test, whose aim is to evaluate the power of the tractor available at the drawbar on a level rigid surface. A DV has to follow developments in technology and must be able to test the tractors' ever-advanced performances, above all forward speed and engine power. For these reasons, in recent years some countries have developed new DVs (i.e. Germany, China, Spain and the USA) for high-power tractors. The present paper reports the engineering of a new DV by the CREA-ING Laboratory of Treviglio, Italy, for carrying out research on tractors with a drawbar power of up to 200 kW (245 kW at the engine flywheel) with a maximum of 118 kN (12,000 kg) drawbar force.

2. Dynamometer design overview

Investigations into traction performances have to solicit drawbar power or traction effort, thus deriving data in order to assess the different constructional features or components of the tractor. Some examples of research topics and the relevant requirements during testing are reported in Fig. 1.

It can be seen that in order to analyse all the parts that go to make up the drawbar performance, a measurement device is needed which can at least: generate a traction effort, counterbalance the power deriving from the tested tractor engine and dissipate the energy produced in order to measure the power. The drawbar force could also be generated by simply towing another vehicle but it may not always be possible to do so at all the different forward speeds, or to dissipate the heat that is generated. As a consequence, a specifically developed device could be fitted with sensors and data acquisition instruments.

2.1. The methodologies based on DVs

Below is a list of the methodologies and standard tests involving DVs in the frame of agricultural research.

2.1.1. OECD Code 2: Testing of agricultural and forestry tractor performance

This standard code indicates how to measure the tractor's performance in terms of power and fuel consumption. One of the main topics is the drawbar test. It indicates the methodology for measuring the maximum drawbar power of an agricultural tractor. A device is needed that can generate a horizontal force at the drawbar of the tested tractor, up to a maximum wheel slip of 15% (Zoz and Brixius, 1979) or the maximum drawbar power, in each gear or speed. It is necessary to measure the force and the forward speed in order to calculate the power at the drawbar, as shown by the following Eq. (1):

$$P_{db}(W) = F_d(N) \cdot s\,(ms^{-1}) \quad (1)$$

where:

- P_{db}: power at the drawbar;
- F_d: maximum force measured at the drawbar in different gears or speeds;
- s: forward speed of the test tractor.