https://doi.org/10.17221/60/2023-RAE

Reconstructed military machinery for unique field testing of agricultural machinery capabilities

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Citation: Szalay K., Souček J., Bércesi G., Bablena A., Kovács L., Nukeshev S.O., Kukharets S., Kravchuk V., Golub G., Machálek A., Dobrinov A.V. (2024): Reconstructed military machinery for unique field testing of agricultural machinery capabilities. Res. Agr. Eng., 70: 53–59.

Abstract: Detailed performance testing of agricultural machinery is very important in determining its value in use. These measurements cannot be limited to laboratory tests, such as braking the power take-off (PTO) shaft of a tractor or performing dynamic tests of implements in a soil bin. Field tests are the ultimate way to test the capabilities of agricultural machinery. However, during such field tests, there are many parameters that can interfere with and affect the test results, such as inhomogeneity of the soil and tyre characteristics. In order to minimise these effects as much as possible, Hungarian University of Agriculture and Life Sciences (MATE) Institute of Technology, Agriculture Engineering Labs. has developed a dynamometer vehicle with an electronic brake control system that is suitable for measuring the traction characteristics of agricultural tractors and other terrain vehicles. It is also capable of testing different track systems and tyre-soil interactions. This paper introduces this special test vehicle by presenting measurement results and also describes other interesting applications for the agricultural community.

Keywords: traction test; tractor field test; dynamometer vehicle

Agricultural machinery performance testing has a long history. Since the mid-19th century, with the rapid growth of mechanisation in agriculture, many testing and research institutes have been established worldwide to help farmers choose the most appropriate machinery solution for their specific needs and help manufacturers identify development trends to make agricultural production more efficient. One of the first institutions was a predecessor of the Hungarian University of Agriculture and Life Sci-

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ences (MATE), Institute of Technology – Institute of Agricultural Engineering (MGI) founded in 1869.

With the growing importance of agricultural tractors, the development of test methods and testing activities began. The first laboratory tests included engine power, fuel and lubricant consumption measurements, and the results were used to determine the optimum parameters. The first field tests evaluated the tractor's drawbar performance. The most prestigious institutes were the Nebraska Tractor Test Laboratory of the University of Nebraska-Lincoln (NTTL) in the USA and the German Agricultural Society (DLG). Still, among others, the predecessor of MGI started testing tractors in the early 1920s (Szente and Vas 2004). However, the results of field tests are influenced not only by the design and the driveline of the tractor (Bashford et al. 1985; Zoz and Wiley 1995) but also by the mechanical properties of the soil on which the tests are carried out (Söhne 1961) and the characteristics of the interaction between the soil and the tyre (or the specific track system) (Söhne 1961; Sitkei 1972; Komándi 1990) soil and implements (Dzhabborov et al. 2018). Therefore, these tests are necessary to obtain proper information about the value of using tractors and terrain vehicles, making their repeatability and reproducibility so difficult.

The current method of measuring the performance of agricultural tractors, approved by several International Standards developed by many organisations (OECD, ISO, ASABE), is to measure the drawbar power over a range of gears on a clean concrete or asphalt surface test track using an instrumented load vehicle (OECD 2017). Many test institutes have developed dynamometer vehicles that meet these requirements, but are unsuitable for field testing. The principle of operation of these dynamometer vehicles is to connect a heavy vehicle behind the tested vehicle by means of a drawbar whose wheels can be controllably braked during the braking measurements of traction parameters, such as drawbar force, speed, fuel consumption, etc., which is necessary to determine these characteristics. Some of them are suitable for loading the Power Take-Off (PTO) system of the tractor simultaneously with the traction test (DLG 2015). The standard procedure for measuring traction characteristics in the field is to use agricultural machinery or another tractor for braking (Figure 1).

These measurement methods of utilisation, energy indicators, and determination of tyre utilisation effect are commonly used to objectively compare tyres of different designs or materials, as stated by the authors of Čedík et al. (2016), where the PneuTrac tyre concept is verified. Using the same method, Čedík and Pražan (2015) verified a novel low-pressure sprayer tyre with a lower inflation pressure and a larger tyre footprint for cases with higher vertical load on the axles. These basic data can be used as a basis for an agricultural tyre evaluation method, as discussed by Prikner et al. (2017).

Figure 1. Various methods of testing tractors in the field

When an unmanned machine is used, the effect of soil inhomogeneity greatly affects the measurement, and in many cases, the measurement of traction force can also be very difficult. With a manned vehicle, such as a braking tractor, in addition to the soil inhomogeneity mentioned above, human error can also affect the measurement. Figure 2 illustrates

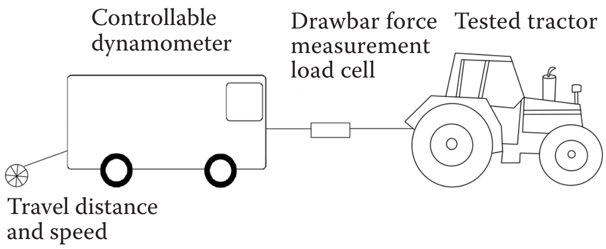

Figure 2. Sketch of the measurement setup for tractor traction tests in the field

https://doi.org/10.17221/60/2023-RAE

the test setup using a dynamometer vehicle for traction testing.

The work aimed to develop and verify that the vehicle was capable of carrying out standard traction tests on tractors and other terrain vehicles, as well as measurements on soft soil. The equipment can be used for research and development purposes in tyre-soil interaction and for testing different track systems.

MATERIAL AND METHODS

Dynamometer vehicle requirements. During the design phase, two modes of operation were identified as the basic requirements for the vehicle. In addition to performing traction tests, the vehicle needed to move independently from site to site.

It was also necessary to be able to carry out traction tests on both rigid surfaces and soft soil.

The required speed range in both modes of operation is 0–35 km.h^{-1}. The required pulling force is continuously variable in the 0–150 kN minimum range. The required drawbar power is continuously variable in the range of 0–250 kW minimum. Two active control modes during the test were also required: a force control mode and a speed control mode with a freely adjustable setpoint value.

Traction characteristics are also strongly influenced by the direction and point of application of the pulling force, so the drawbar on the dynamometer vehicle must have an adjustable connection height.

Construction of the vehicle. The base vehicle for constructing the dynamometer vehicle is a MAZ 537 military truck tractor, shown in Figure 3, originally designed to pull heavy loads of up to 50 tonnes. Its weight was originally about 22 t, with a payload capacity of 7 t, an 8 × 8 drive chain, independently suspended wheels with excellent off-road capabilities and sufficient weight for high tractive force. The cabin seats 3 passengers plus the driver, which makes it suitable for a measurement crew, and the built-in instrumentation (MAZ-537 documentation).

Figure 3. MAZ 537 military truck tractor used as a base for the construction of the dynamometer vehicle

To make it suitable for use as a dynamometer vehicle, the following modifications were made to the vehicle:

The original engine was replaced with a 400 kW IVECO V8 cursor engine; the original transmission system was replaced with a hydrostatic one; a programmable electronic system was installed to control the driving parameters; a drawbar system with a hydrostatic height adjustment and integrated load cell was fitted to the front of the vehicle.

Figures 4 and 5 show the finished dynamometer vehicle.

Operation of the machinery. The dynamometer vehicle is a self-propelled vehicle operating with a hydrostatic drive. The pump unit is coupled directly to the flywheel of the diesel engine via a clutch so that its speed is the same as the engine speed. The pump unit has two pumps with a common axle but with independent suction and pressure lines. The first pump is an axial piston variable pump with

Figure 4. Development of the drawbar

Figure 5. The dynamometer vehicle ready for measurement

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a swashplate, and the second is a boost pump that acts as a feed pump. The vehicle's wheels are driven via two axial piston variable hydraulic motors mounted on the driveline's internal gearbox. Another separate gearbox in the driveline provides two speeds. The auxiliary pump prevents the diesel engine from accelerating if its torque is insufficient to eliminate the set braking torque.

The dynamometer vehicle control software is designed to control the hydrostatic drive system to maintain a constant speed and braking (pulling) force, which can be adjusted by the operator using a toggle switch while the vehicle is being pulled. A separate hydraulic braking circuit provides additional braking force with a hydraulic motor and a proportional pressure valve, which is also proportionally controlled. Actual and set values of the braking force and speed are shown on the human machine interface (HMI) display. There is also a normal driving mode in which the accelerator pedal controls the speed.

The software also monitors the pressure in the hydrostatic drive circuit, diesel acceleration and diesel overload during the braking and normal driving modes. It adjusts the speed (conditions) to keep the machine parameters safe. A block diagram of the machine control components is shown in Figure 6.

The main control unit of the system is a Rexroth Bodas Controller (RC Series 20 type, Bosch Rexroth AG, Germany) controller specially designed for hydraulic systems. An HMI display unit is connected to this controller via CAN bus, which displays the setpoint parameters and contains switches for setting them, as well as the operating mode (driving or braking) and the machine's controlled parameter (speed or force). The inputs to the system are the accelerator pedal angle sensor, the drawbar force sensor, the oil pressure and temperature sensors, and the speed sensors of the diesel engine and hydraulic motors. The actuators are axial-piston bent-axis variable hydraulic motors with a pressure relief valve.

In driving mode, the driver is in full control of the vehicle and the accelerator pedal controls the speed. The desired speed in the normal driving mode is reduced by load limit control. The load limit is evaluated by the drop in the engine speed compared to the known curve of speed versus pedal angle.

In break mode, another vehicle pulls the vehicle, and the controller algorithm controls the speed or force (depending on the operator's choice). The speed of the vehicle is closed-loop controlled by setting the value of the speed or force (set by 2 switches, set UP and set DOWN). The sensitivity (scaling) of the control is adjustable. The braking force signal is provided by an external sensor (mounted on the drawbar) which measures the braking force. The PID parameters for the control are also adjustable.

The operating states of the vehicle are as follows: (·) Start locked: waiting for start conditions after power up; outputs are not active; indicated by flashing error indicator. (·) Parking mode: no drive direction has been selected; the vehicle is stationary; outputs are set to minimum values. (·) Driving forward mode: driving forward is possible; speed depends on the signal from the accelerator pedal. (·) Reverse mode: driving backwards is possible; speed depends on the signal from the accelerator pedal. (·) Force braking mode: the force controller is active and con-

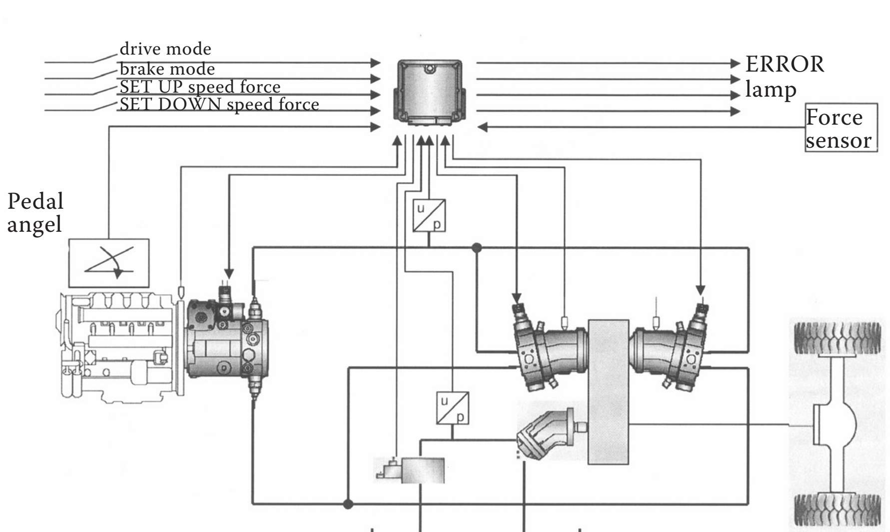

Figure 6. Main components of the dynamometer vehicle drive and control systems

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trols the speed of the vehicle to set force setpoint values; only forward driving is possible. (·) Speed braking mode: the speed controller is active and controls the speed of the vehicle to set the speed setpoint values; only forward driving is possible. (·) Fault detected: information on the type of fault is displayed; the reaction depends on the driving mode.

The machine's drawbar system has an independent manual control. This system consists of a small electric hydraulic pump unit with its tank, two manually operated lever valves, and three hydraulic cylinders. Two of these – one on each side – adjust the height by lifting the drawbar joint up and down. The third is used to set the drawbar's horizontal position and support it before it is connected to the vehicle being tested. When the vehicle needs to be driven independently, the cylinder can be disconnected and the drawbar is set vertically.

The dynamometer vehicle (Fenyvesi et al. 2014) is a useful machine for controllable loading of the tested vehicles even under field conditions. Still, it does not have an integrated measurement system, as the number and type of measurable parameters depend highly on the specific measurement task. It is, therefore, necessary to install an independent data acquisition system for the measurements. There is a suitable space in the cabin of the dynamometer vehicle for the installation of a measurement laptop and cables. Several parameters can be measured, but the most common are the drawbar force, driving speed, distance travelled, circumferential speed of the tested vehicle's driven wheels, and the tested vehicle's fuel consumption (Figure 7).

The drawbar force is measured with a 200 or 500 kN load cell manufactured by HBM GmbH. The driving speed is measured by Doppler radar, freewheel with

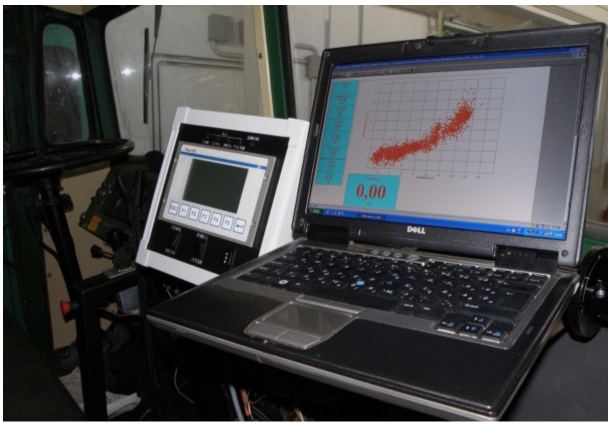

Figure 7. Control panel and measurement laptop in the cabin of the dynamometer vehicle

an encoder, or by GPS. PLU type flow sensors are used to measure fuel consumption. High-precision Sipder8 measurement electronics from HBM GmbH and a measurement laptop are used for data acquisition. This allows different sensors to be connected, the appropriate sampling frequency to be set and the measured data to be displayed in real time. Figure 5 shows the operator's seat in the dynamometer vehicle with the HMI and the measurement laptop.

Measurements are typically complemented by environmental sensors to continuously record meteorological parameters, soil sampling equipment to collect soil samples for further analysis, and penetration loggers to map soil properties on-site.

RESULTS AND DISCUSSION

The dynamometer vehicle offers the possibility of a wide range of specialised tests. In addition to standard drawbar (traction) tests, other tractor parameters can be tested for further development. Relevant features are the following:

(·) Drawbar testing on a field. (·) Continuous testing of tractor operation, traction and drawbar performance at a given driving speed. The dynamometer vehicle provides a constant (stable) driving speed (speed control), and the inputs to the test tractor are variable. (·) Continuous testing of tractor operation, traction and drawbar performance at a given drawbar force. The dynamometer vehicle provides a constant (stable) drawbar force (force control), and the test tractor inputs are variable. The drawbar force requirement (i.e. the average of it) of a given towed implement can be simulated with the appropriate choice of the drawbar force.

The above tests can also be adapted for the testing of trucks and terrain vehicles.

In addition to testing machine performance, the method can also be used for testing track systems, tyre-soil interaction, energy efficiency of tractors, tyres (Bércesi et al. 2017; Baranov 2019), and related fundamental research topics.

Testing and model validation of the developed implements and related basic research (Fenyvesi and Hudoba 2010; Keppler et al. 2015, 2016; Semenchuk et al. 2018)

During the experimental testing of the dynamometer vehicle, it was found that with this method, the same performance characteristic curves can be recorded in two ways when the tested tractor is equipped with a 'common' powershift transmission. The first

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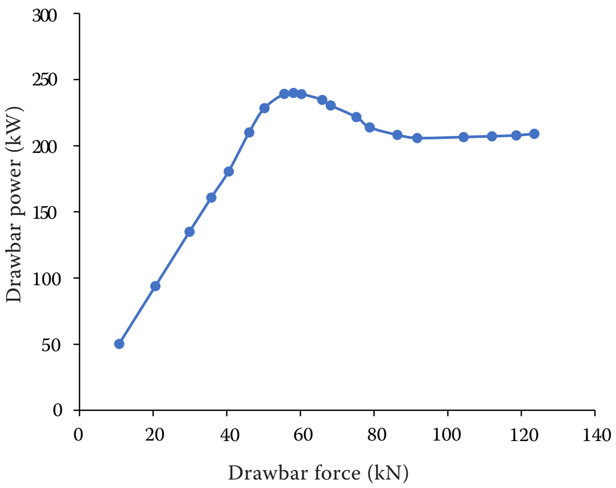

Figure 8. Drawbar curve from an experimental tractor measurement

is to carry out the tests step by step, setting and maintaining the load values from zero to maximum value for a short period and fitting a curve to the averaged measured values at the same point. The second option is to fit a curve to the recorded data of continuously increasing/decreasing load values.

Figure 8 shows a processed traction curve dataset from an experimental measurement carried out with the dynamometer vehicle.

CONCLUSION

The existing equipment is a robust platform with broad field testing capabilities. However, the dynamic development of IT-supported, or rather, IT-based agricultural machinery and equipment may result in even more complex test methods to determine the value in use of the machinery and the need to implement an updated or completely new system. The equipment and the unique test methods can become a valuable asset for the practical unification of national and international standards, and for carrying out certification, comparison, or development field tests. The advantage of the developed dynamometer vehicle compared to standard measurement equipment is that it can be used to test vehicles with a higher performance. This can be useful in the field of agricultural technology, but also in other fields, such as forestry, transport, construction, etc.

Acknowledgement: The authors would like to thank Dr. László Fenyvesi, Dr. Márk Szente, János Elek, László Dudás, Dr. Attila Csatár, and the Bosch-Rexroth Ltd. for their scientific and technical contributions to the design, construction and operation of the machinery. The authors would also like to thank the national and international partners for the valuable exchange of knowledge and experience during the field tests. The article was created with the support of the long-term development project of the Research Institute of Agricultural Engineering p.r.i.

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Received: February 7, 2023
Accepted: September 26, 2023
Published online: March 12, 2024