Ammonia as carbon free fuel for internal CombusTion engIne driVen AgriculTural vEhicle

ACTIVATE

Work Package 2
Deliverable Report

Topic: D2.2

Operational characteristic for the target agricultural vehicle operated under indoor and outdoor conditions

30.06.2021

Programme operated by: The National Centre for Research and Development

Project consortium: Silesian University of Technology, NTNU Norwegian University of Science and Technology, LOGE, University of Agriculture in Krakow

1 Agriculture vehicle presentation

The subject of the research was a Scout T-15 tractor what presents Fig. 1.1. It is factory-fitted with a single-cylinder 815 cm3 diesel engine. This unit generates 14.85 hp (10.92kW), which is sufficient for most of the simple field and transport work. Power from the engine is transmitted by two belts, which transfer the power to a pulley in the rear of the tractor. The power is then transferred to a clutch and a gearbox. The tractor has 3 forward gears and 1 reverse gear. Each of the gear ratios has two variants: a road allowance (H) and an off-road allowance (L). The type of transmission depends on the setting of the geared motor, which additionally changes the ratio.

Figure 1.1: Scheme of the new engine mounting plate

1.1 Engine swap

Due to the lack of availability of this engine, it was necessary to replace it with another engine with similar parameters. In this case, the choice fell on the well-known and widely used compression ignition engine type L-100 - LiFAN - 186F. Detailed parameters of this engine are presented in the table:

- Engine type - four-stroke, air-cooled
- engine displacement - 418 cm with power 9,5 hp (6,8 kW) / 3,600 rpm
- engine start - manual and electric
- fuel - diesel ON
- diameter x stroke - 86x75
- combustion - direct injection
- lubrication type - oil pump
- capacity of tank - 5,5L
- capacity of oil sump - 1,65L

- net weight - 53 kg
- shaft diameter - 25.4 mm.
- starter cables included
- oil air filter

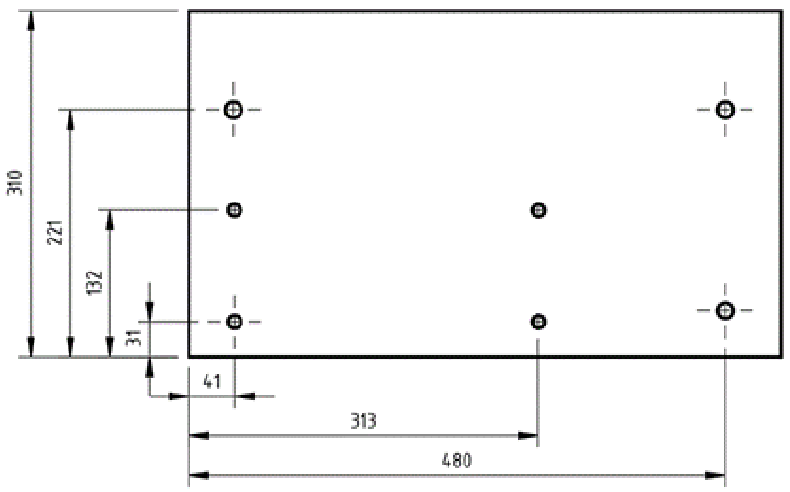


Figure 1.2: Scheme of the new engine mounting plate

On the Fig 1.2 is shown sketch of the new mounting plate for the single cylinder engine. This part was made from 6mm steel. The Fig. 1.3 shows mounted unit on the tractor. As new engine is more than three times lighter than old one, there was need to compensate this change in weight distribution of the tractor, as during agricultural operation this change could lead to hazardous situations. After consultation, in accordance to simple calculations, 40kg concrete element was chosen to compensate weight loss and prevent lifting of the front wheels. The look for the tractor front with weight on it presents Fig. 1.4.

2 Sensors selection

To carry out the research planned in WP2, it was necessary to develop a measurement system capable of measuring and recording a range of data necessary to calculate quantities such as power and torque. As a result of the work carried out, a list and proposed layout of the most important measuring systems was drawn up (Fig. 2.1.

2.1 tractive force sensor

The most important quantity for determining power and torque is the force required to perform a given action. Due to the nature of the work planned, a strain gauge system is proposed, with

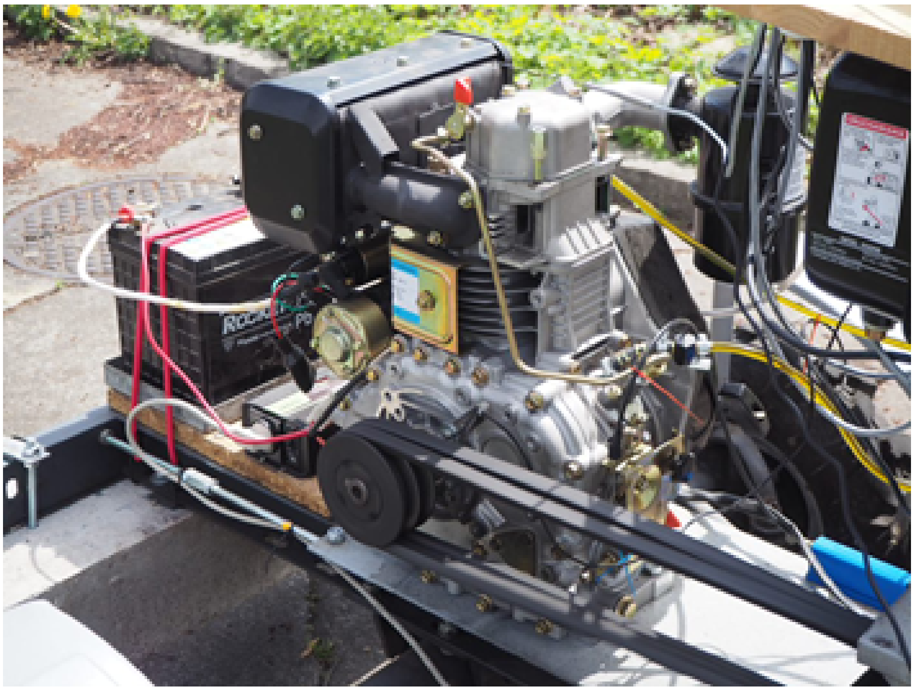


Figure 1.3: View on the retrofited engine

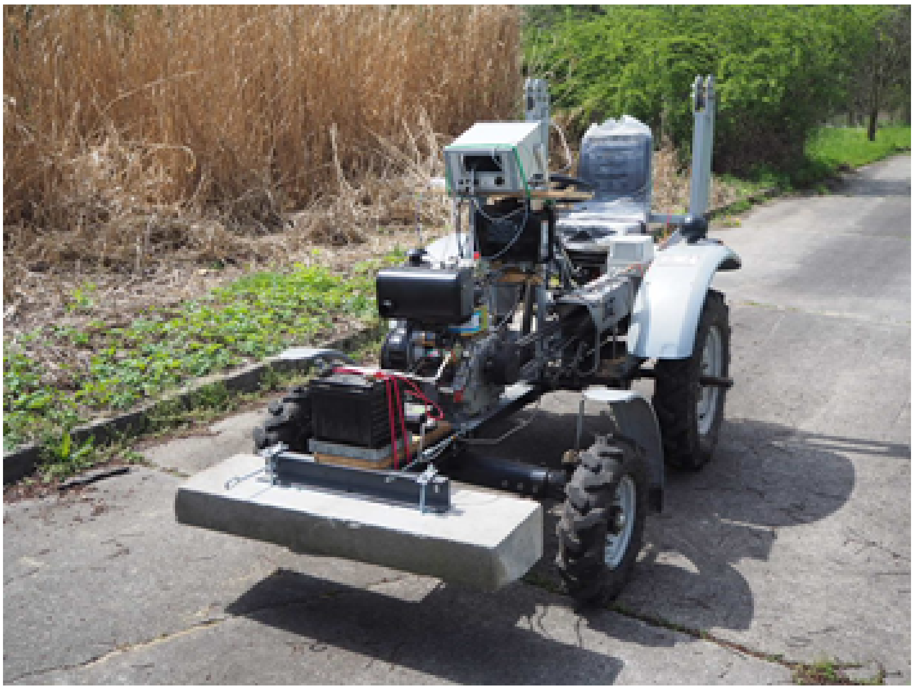


Figure 1.4: View on the front of the tractor

an S-type strain gauge at its heart. Based on experience from similar studies, in order to ensure an adequate reserve of the measuring range, a strain gauge system with a maximum load of 7.5kN was proposed. The sensor was connected to a signal amplification circuit, which allows the use of a standard 4-20mA signal type.

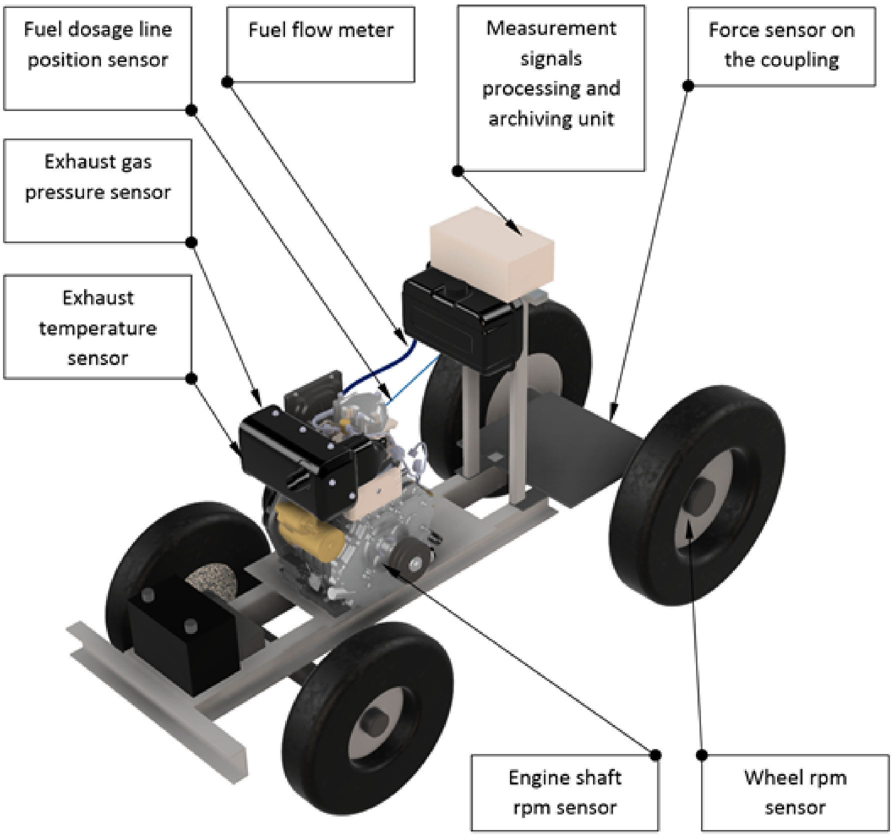


Figure 2.1: View on placement of most important sensors

2.2 Engine and wheel speed estimation

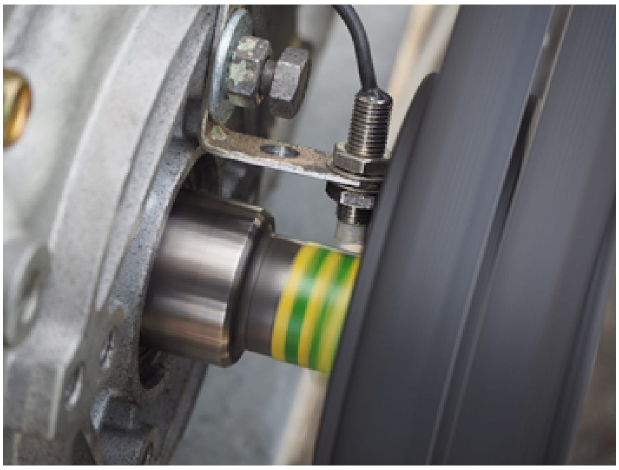
Other important measurement quantities were the rotational speeds (RPM) of the engine shaft and wheels. Simple inductive sensors were used to determine these quantities. The reason for this was that, especially in the case of the engine, the use of more advanced measurement methods such as Encoder was not possible due to limited space. View of the sensors, presents Fig 2.2

As both sensors provide a signal which, based on the measuring equipment, is converted into pulses per minute, it is possible to determine the number of revolutions per minute.This value is useful in the case of the engine shaft, whereas in the case of wheel speed, it is necessary to convert these revolutions into distance/road, which allows, based on the number of cycles per unit of time, to determine the speed of the tractor

2.3 Other sensors

Due to the need to verify the field tests under laboratory conditions, there is a need to determine the engine settings at a given operating point. Due to the fact that, unlike in the case of a spark ignition engine, it is not possible to read the throttle setting, controlled by the throttle cable, it was necessary to propose another way of reading the parameters necessary to determine the exact operating point of the engine. For this purpose, a cable-mounted attachment was designed and manufactured in FDM technology. A linear potentiometer was mounted in the attachment to determine

(a) wheels



(b) engine

Figure 2.2: View of the inductive sensors

the position of the throttle cable, and thus the engine setting. The measurement of fuel flow is a very important parameter. For field tests, a flow meter must be used. Preliminary estimates, based on engine power, and fuel energy value, determined the expected operating range of such a flow meter. The expected flow rate should be below 0.1l/min. After market analysis, a rotor flowmeter (Fig. 2.3 was used, allowing flow readings in the range of 0.01-0.9 l/min.

Figure 2.3: View on chosen flow meter

2.4 DAQ system

All signals from the measuring devices were transmitted in a form that could be processed by data visualisation and processing equipment. The SIMEX CMC99 was selected as the central unit for data capture and processing. This device allows flexible selection of the parameters to be measured, by using appropriate input cards. The entire device was protected from external influences by means of a suitable casing, which was mounted at the height of the tractor's steering wheel, as illustrated in Fig. 2.4. In addition, the software implemented in the device allows the use of advanced commands, which gives the possibility of converting measured values into useful values.

Figure 2.4: View on the single DAQ system

More detailed data flow presents Fig. 2.5

The entire measurement system was powered by an AC-DC converter connected to a 12V battery, Fig. 2.6

3 Methodology

3.1 Realized scenarios

Travel with trolley The main scenario of the study, trailer driving, was selected. The low power of the installed engine and the low weight of the tractor make it undesirable to use it for heavy field work. Due to the small dimensions, it seems reasonable to use this type of equipment for on-farm transport of e.g. fruit or other crops. For this reason, a route was selected on an internal road within the university campus. A detailed map with the elevation profile is presented in fig. As can be seen, the route mostly runs on flat terrain and the route is covered with asphalt. This choice of surface was mainly due to the necessity of limiting the influence of ground conditions on the measurement

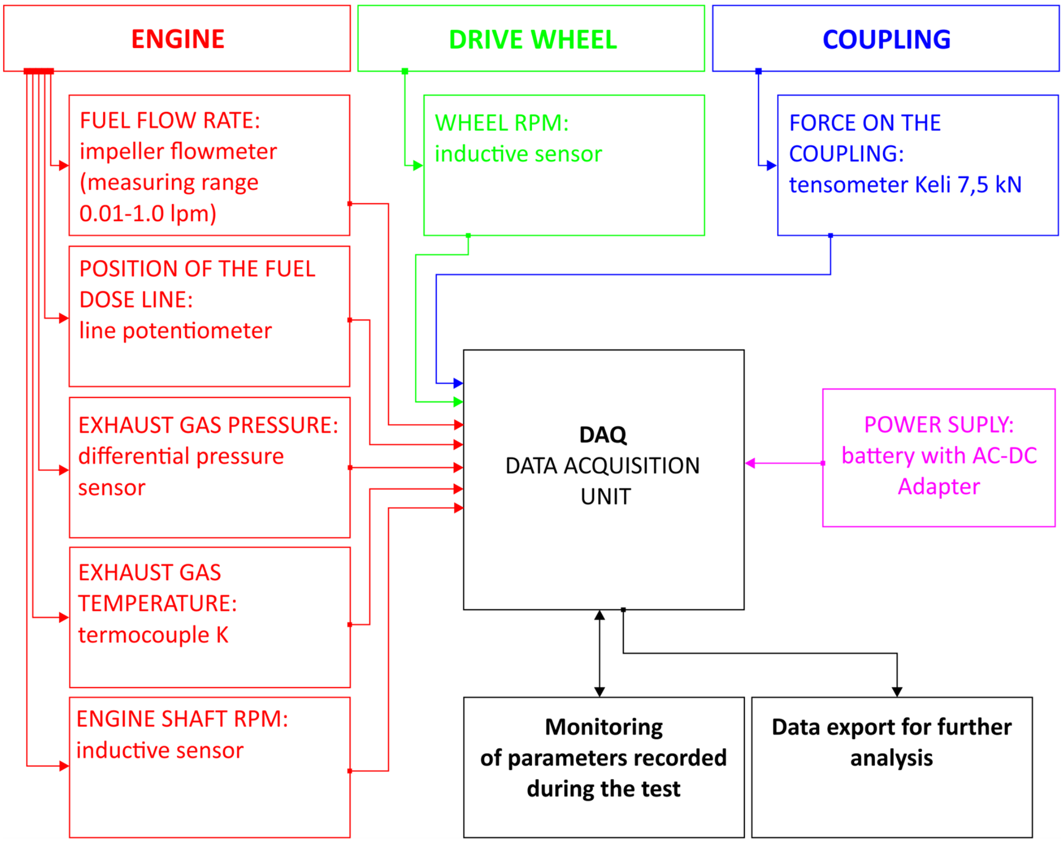


Figure 2.5: Flow of the signals in DAQ system

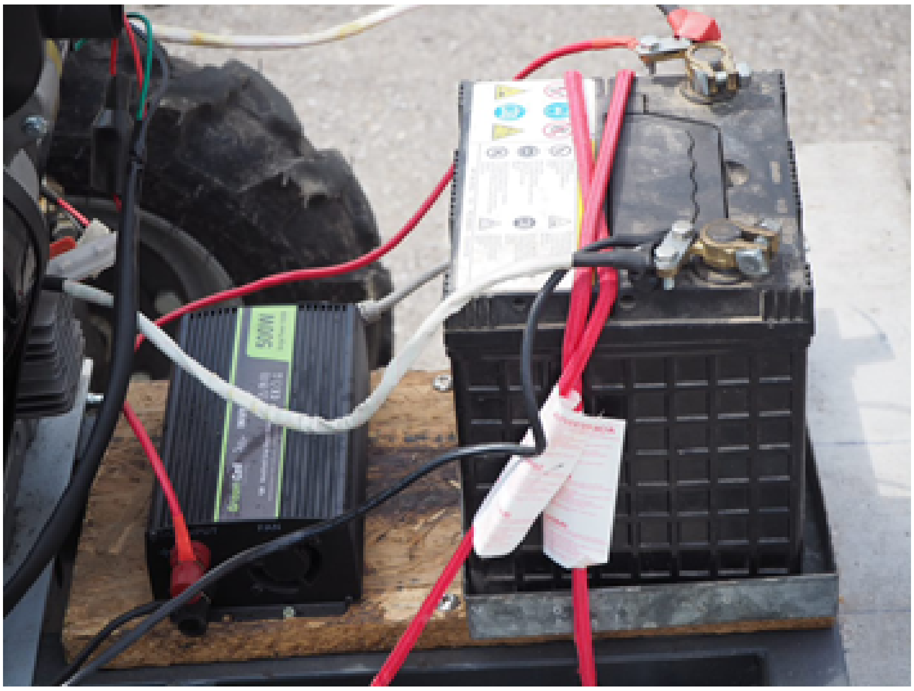


Figure 2.6: View on AC-DC converter and 12V battery

data. The scenario included driving an empty and a loaded trailer (load mass 200kg) The test were made in different speeds, for test purposes 5,7 and 10 km/h were selected.

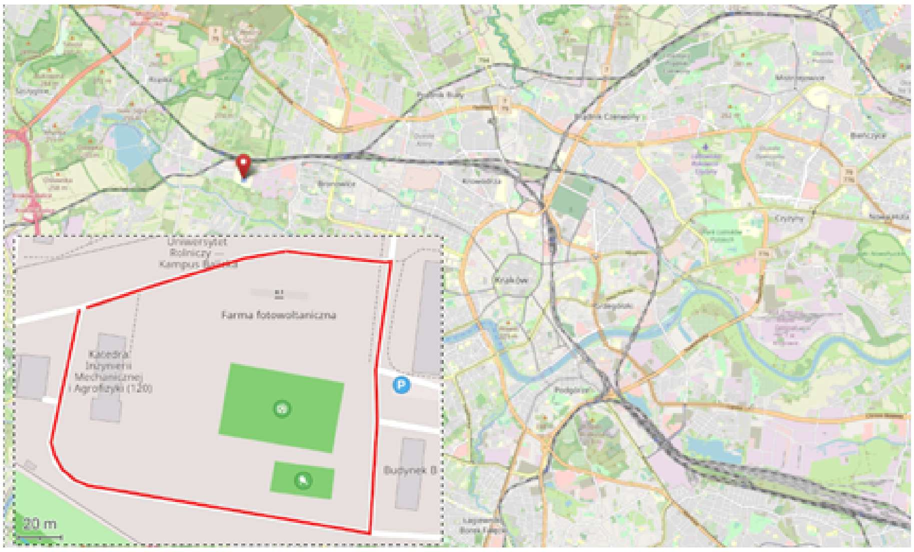


Figure 3.1: Map of trolley test track

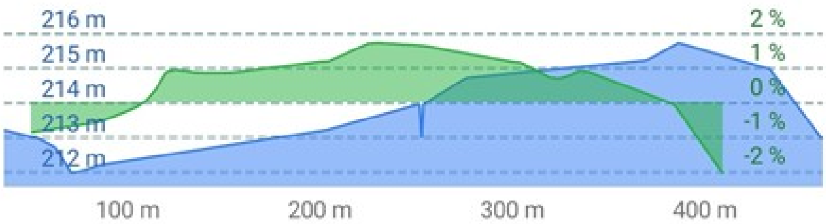


Figure 3.2: Profile of trolley test track

Agriculture operations - plowing

3.2 Data curation - power and torque

The key information from the tests carried out under operating conditions (field work, transport) is the value of the engine torque under the various operating conditions (speed, load, etc.). The following presents the calculation procedure for determining the engine torque value.

In order to determine the structure of the work performed by the driving unit, the key values of forces necessary to perform the planned tests were determined, i.e:

- the force needed to overcome the rolling resistance and the losses in the transmission mechanisms (gears, clutch), denoted as F_t, $[N]$

(a) empty troley

(b) loaded troley

Figure 3.3: View of tractor with trolley

Figure 3.4: Map of plowing

- the force at the tractor's coupling point, understood as the operating resistance of the operations carried out F_z, $[N]$

The determination of these forces was done by strain gauge measurement. The sum of the above mentioned forces

$$F_c = F_t + F_z$$

determines the working resistance of the tractor + machine set. This value was the basis for calculating the work L, $[J]$ at a given time t, $[s]$

$$L = F_c \, s$$

where: L - work done by the drive unit during the test period,
F_c - total resistance force
s - unit distance during the test in the adopted time intervals $[m]$.

(a) (b)

Figure 3.5: View of plowing operation

During the test, current measurements are taken of the tractor speed $V,\ [m/s]$ at assumed time intervals t. Based on this information, the distance s [m] was determined

$$s = \frac{V}{t}$$

For the work L calculated in this way, it was possible to calculate the actual engine power $P,\ [W]$ at the analyzed time intervals from the following relation:

$$P = \frac{L}{t}$$

The motor power calculated in this way was used to estimate the motor torque $M,\ [Nm]$ at a specific shaft angular velocity $\omega,\ [rad/s]$

$$M = \frac{P}{\omega}$$

The value of the angular velocity of the motor shaft was determined based on the rotational speed $n,\ [rpm]$ achieved during tests

$$\omega = \frac{(2\pi\ n)}{60}$$

The estimated values of the engine torque could be used for further analyses taking fuel consumption into account.

3.3 Chassis dynamometer tests

The next stage of the research was to carry out a test under controlled conditions to determine the performance characteristics of the engine, with particular reference to exhaust gas composition and temperature. For this purpose, a MAHA Chassis dynamometer was used, which allows stable operating points to be set. Gear 3 was used as the most suitable gear for this type of analysis. Six engine loads (tractive force) were analysed, for four different engine speeds, thus covering practically the entire operating range of the engine. The configuration of the measurement points is summarised in TableXX. Flue gas composition was measured with use od Infralts N gas analyser (Saxon Junkalor GmbH). The power and tractive force was noted from the computer screen connected to the chassis dynamometer test.

4 Results

4.1 Field test

Figure 4.1 shows examples of the power and torque values obtained when driving with the trolley at full load. In order to present the results, 3 speeds have been distinguished, which represent the different phases of the tractor's operation. The presented results confirm the correlation that the power required for propulsion will increase with increasing speed. However, the torque is similar at 8.1 and 11.5 km/h. A different data set was obtained for ploughing (Fig 4.2). In this case, the highest power was obtained for lowest speed. The upward trend for torque, although clear, is worth considering the scale for this variable, which oscillates within the measurement error of the equipment. Therefore, it can be assumed that torque is equal in this case for all three analysed operating points.

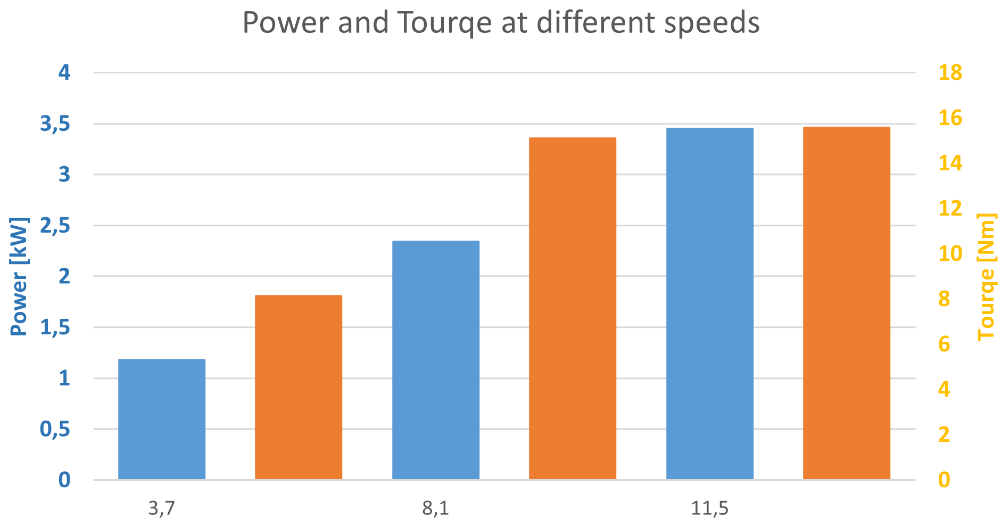


Figure 4.1: Dependency of Power and Torque in different speeds of travel with trolley

4.2 Chassis dynamometer test

Figure 4.3 shows the power values at different operating points. The green colour indicates the values obtained for the maximum brake loads of the dynamometer, which (600-650N). When analysing the curve of power change with the engine speed, it is easy to see that the highest power is generated by the tractor at the engine speed above 3000 RPM. This relationship is consistent with the data found for L100-type engines. The analysis of torque obtained torque (Fig 4.4) shows that

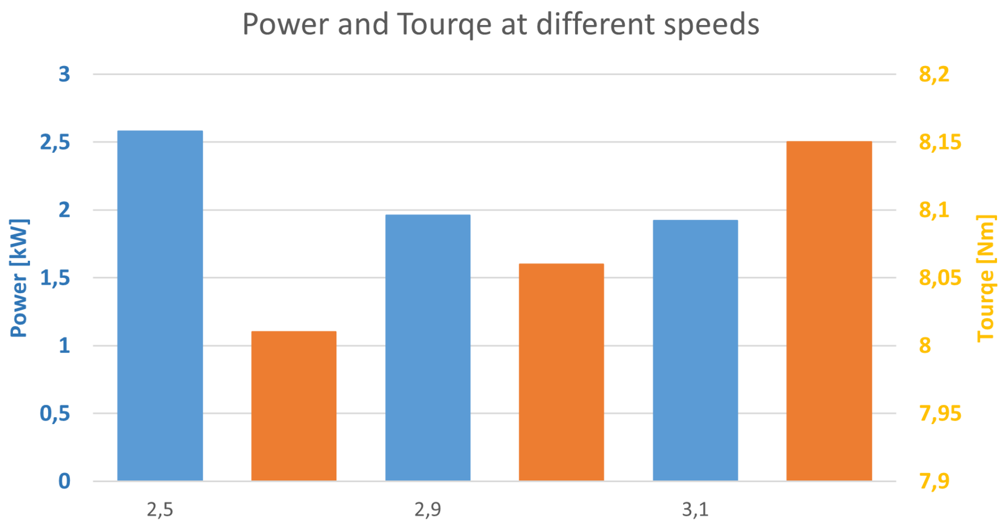


Figure 4.2: Dependency of Power and Torque in different speeds during plow operation

the highest values were obtained at lower values of rotational speed, which is also consistent with the characteristics found for this type of unit.

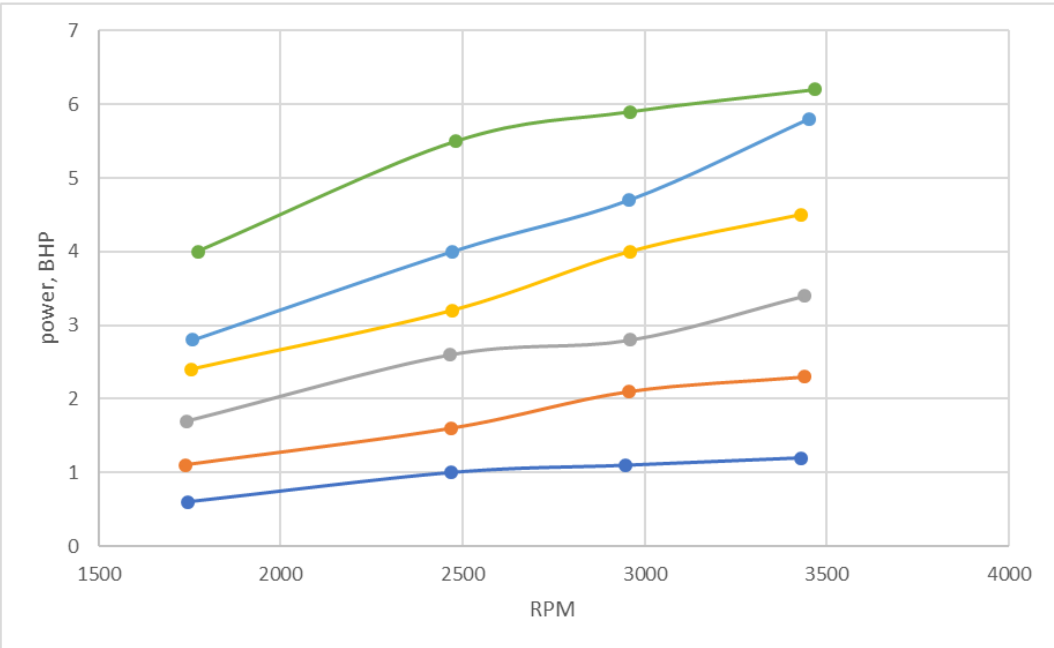


Figure 4.3: Power of the vehicle at different loads and engine speeds

Figures form 4.5 4.9 presents exhaust gases composition. On the basis of the data collated, it can easily be seen that within the maximum engine loads, the quality of the exhaust gases emitted deteriorates drastically. In particular the emission of carbon monoxide (Fig 4.5) and organic compounds (Fig 4.8). It is worth mentioning that at low speeds (1700-2500rpm), the shares of these two exhaust gases components are very unfavourable. The analysis of NO-NOx (Fig 4.7) emissions

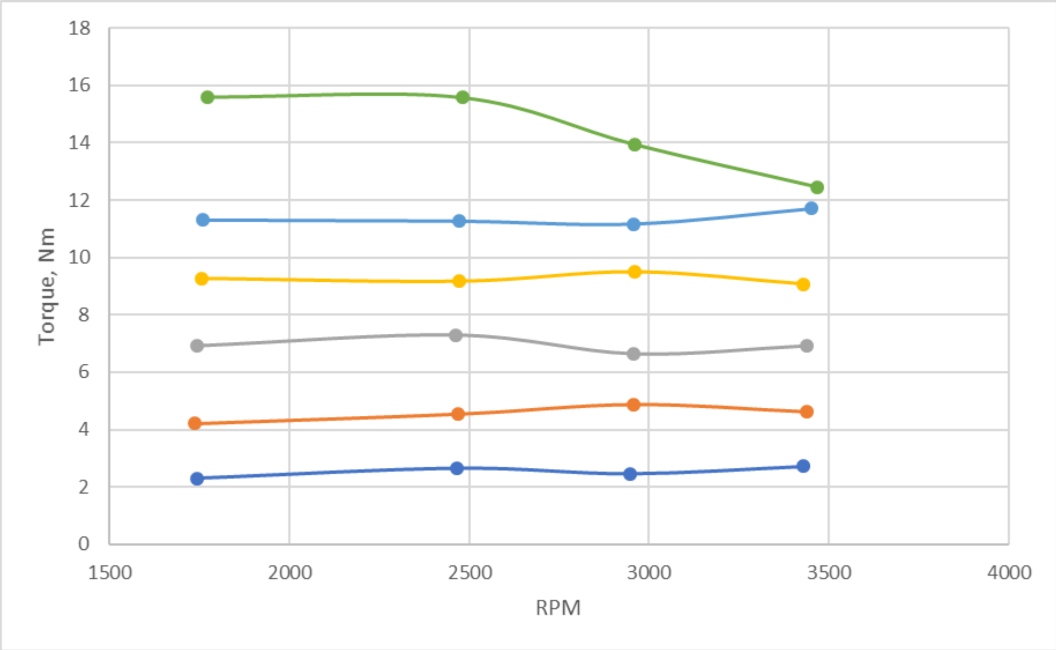


Figure 4.4: Torque of the vehicle at different loads and engine speeds

showed that, as in the case of the previous components, the proportion of nitrogen compounds in the exhaust gases is lower for higher values of engine speed.

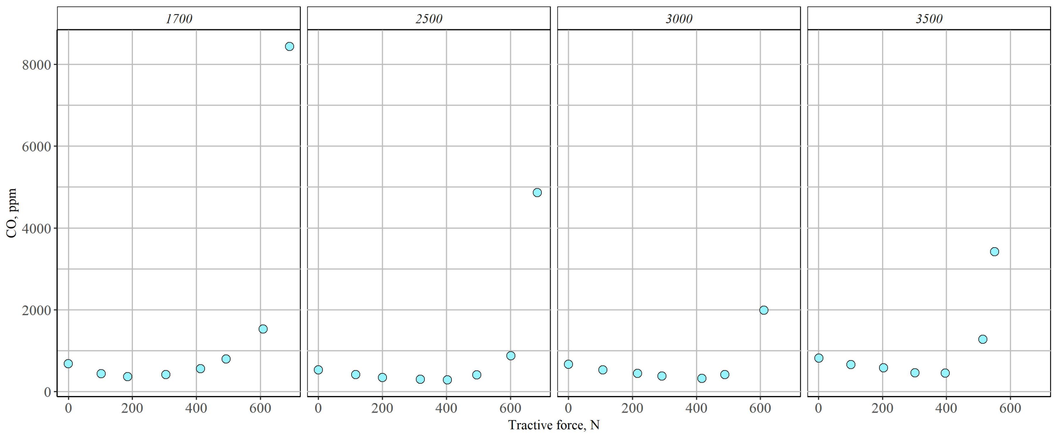


Figure 4.5: Share of CO in flue gases during test at different loads and engine speeds

The last parameter which is important in terms of peripheral systems (SCR exhaust gas denitrification system) is the exhaust gas temperature (Fig 4.10). It is crucial in order to ensure proper conditions for catalytic reactions and should be at least 250°C, but optimally the temperature in the reactor (depending on the manufacturer) should be 300-400°C). It is evident from the diagrams (Fig.), that in case of a diesel fueled engine, ensuring optimal process conditions will be very difficult, therefore, at these points (if data are confirmed for an ammonia fueled engine), it will be necessary to apply a reactor heating system.

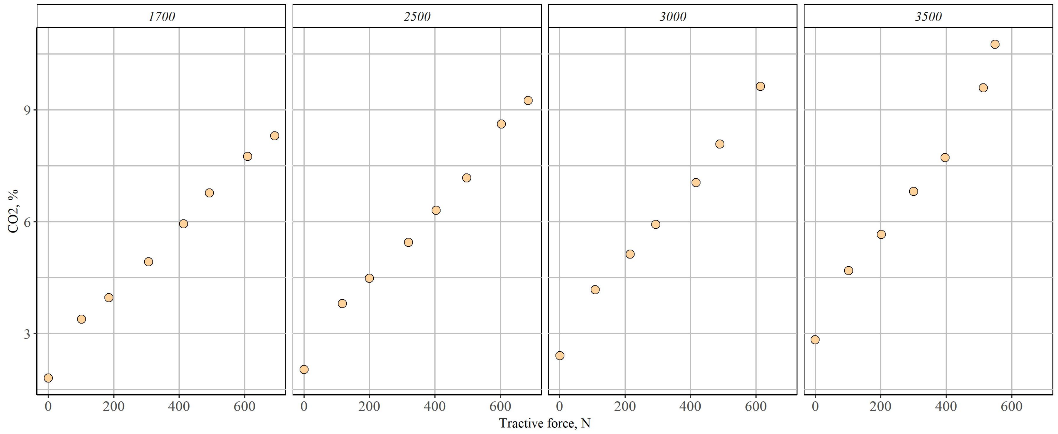


Figure 4.6: Share of CO2 in flue gases during test at different loads and engine speeds

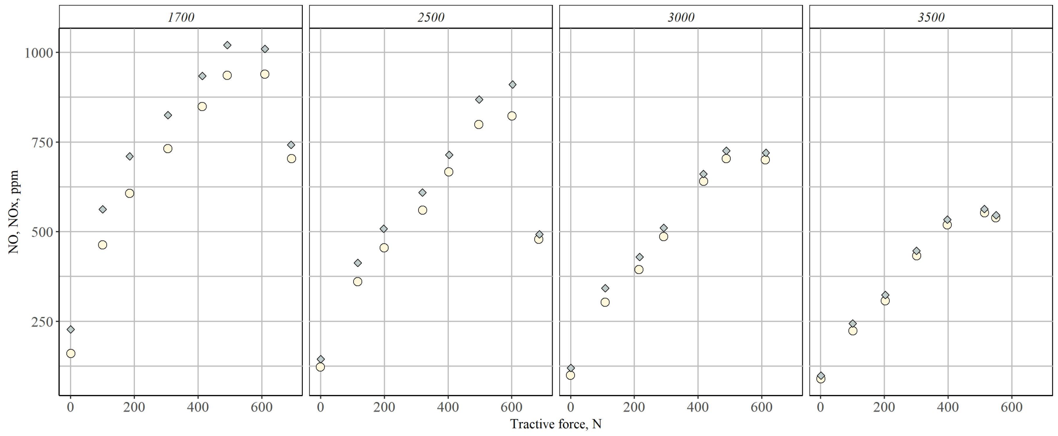


Figure 4.7: Share of NO and NOx in flue gases during test at different loads and engine speeds

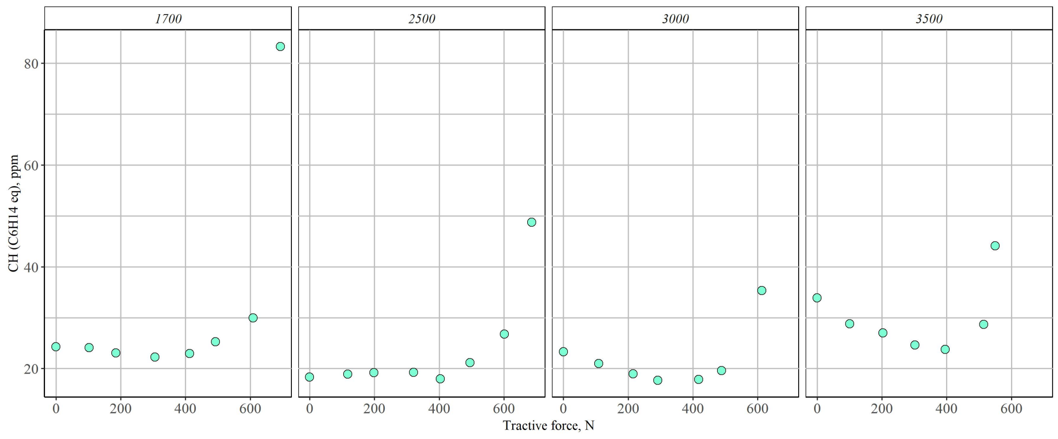


Figure 4.8: Share of hudrocarbons (CH) in flue gases during test at different loads and engine speeds

5 Summary

The work presented was based on the design of a measurement system allowing for the measurement of basic tractor parameters in field conditions. Tests were carried out for two field operations

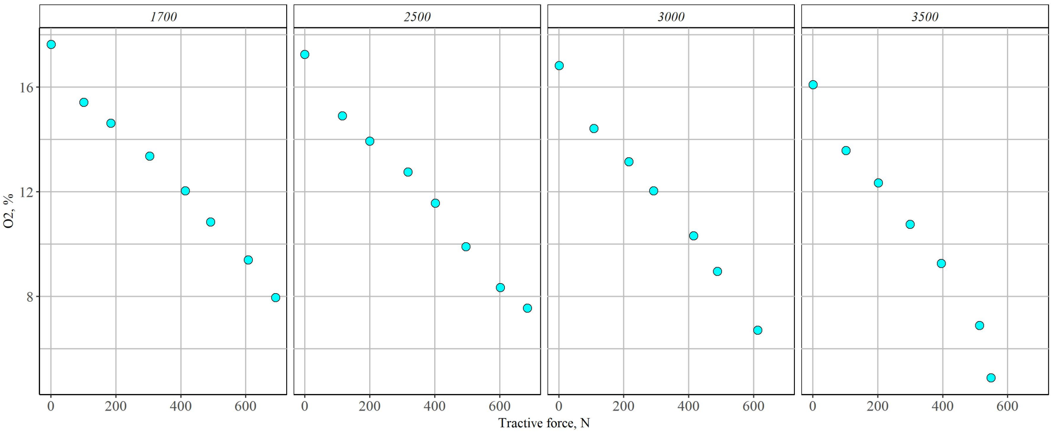


Figure 4.9: Share of O2 in flue gases during test at different loads and engine speeds

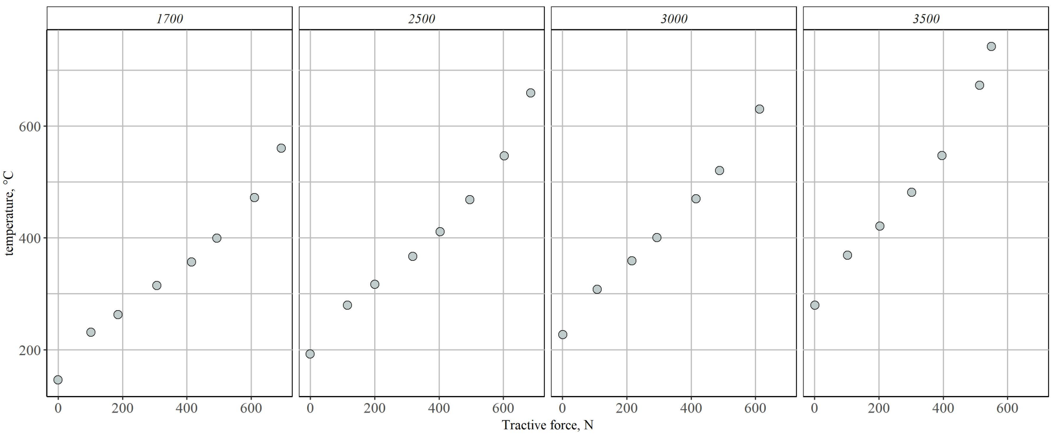


Figure 4.10: Flue gases temperature during test at different loads and engine speeds

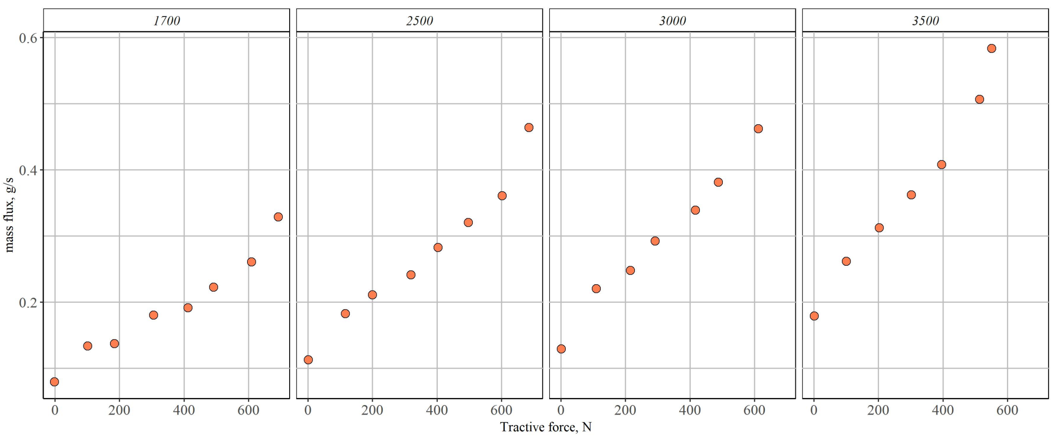


Figure 4.11: Fuel consumption during test at different loads and engine speeds

characteristic for this type of equipment, i.e. driving with a trolley and working with a light plough. In both cases, several speed variants were analysed. The next stage was the analysis of operating points on a chassis dynamometer, where it was possible to precisely analyse the composition of exhaust gases. Twenty-two operating points were analysed, for various engine loads and speeds. The results of the field tests made it possible to collate the working points of two field processes characteristic of this type of tractor. The results in comparison with the device characteristics show that these points are located in the zone of medium loads of the device, which seems to be favourable in relation to the exhaust gas analysis performed on the chasis dynamometer. Referring to the exhaust gas analysis results, it is worth mentioning that the engine used is a system which seems to work optimally at higher values of engine rotational speed (above 3000 RPM). The analysis of the exhaust gases showed that at higher loads and speeds, it will be possible to use the SCR system to reduce nitrogen oxides.