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# AMMONIA AS CARBON FREE FUEL FOR INTERNAL COMBUSTION ENGINE DRIVEN AGRICULTURAL VEHICLE

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## ACTIVATE

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Work Package 2  
Deliverable Report

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**Topic: D5.1**

REPORT FROM TRACTOR RETROFITTING PROCESS FOR AMMONIA COMBUSTION

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# 1 Adaptation of the tractor to $NH_3$

The goal of this Deliverables is to present the fully functional agricultural vehicle with ammonia fueling system.

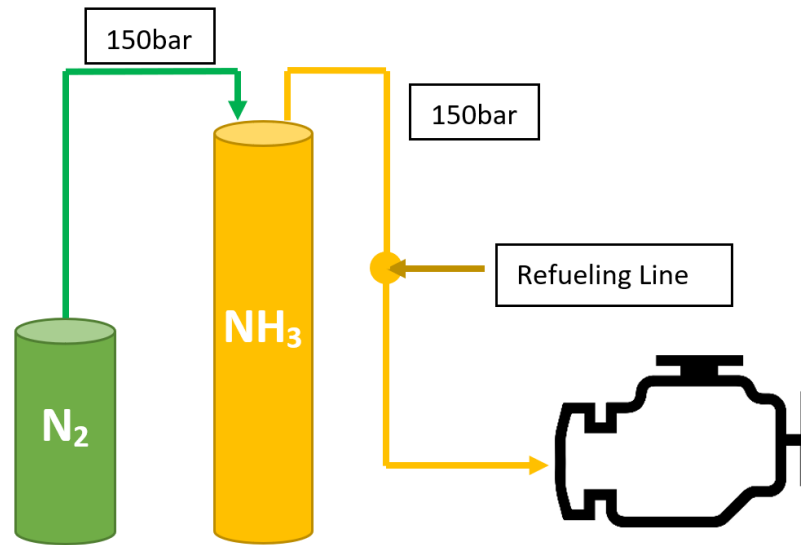
## 1.1 Design of a tractor-mounted ammonia distribution system

Pilot tests on an engine dynamometer were an important point in the planning process for an ammonia fueling system. Due to the complicated design and high dead weight, the use of the built line used to supply the engine during the engine dynamometer tests was abandoned. It became necessary to design and build a fuel line adapted to the tractor's existing design.

- low weight of the system
- compact size so as not to limit front visibility
- ability to work in contact with ammonia
- ability to work in a high-pressure system (150bar)
- safety system in case of large system leakage

### 1.1.1 Ammonia transport concept

Due to the characteristics of ammonia, in avoiding intense evaporation, it is necessary to maintain adequate pressure in the system. Depending on the ambient temperature, the pressure inside the cylinder (system) should be higher than 10 bar. In order to reduce the weight of the designed installation, it became necessary to use a smaller cylinder than originally planned. Tests on an engine dynamometer, showed that sufficient ammonia for several hours of engine operation is about 2-3kg. This amount is possible to refuel into a 10L cylinder. Another aspect that needed to be solved at this stage was the intake of ammonia from the cylinder. Due to the low evaporation temperature, and relatively high saturation pressures, in order to draw ammonia in the liquid phase, it must be sucked from the bottom of the cylinder. In order to avoid evaporation of the fuel inside the cylinder, which is caused by the increasing volume of the gas phase (pressure drop), it is necessary to compensate for this by injecting an inert gas. The natural choice in this case would seem to be nitrogen. This forces the use of a second, smaller cylinder for this gas. At this stage 5L vessel was chosen. The conceptual scheme of the installation is shown on Fig. 1.1 In industrial applications for ammonia storage, two-outlet valves are common. Such valves have a nozzle for the liquid phase, which is drawn in from the bottom of the cylinder through a spout pipe. The other nozzle, is mainly used to drain the gas phase, however, it can also be used to introduce inert gas. An example of such a valve is VTI's model K-47, the diagram of which is shown below. Importantly, this valve is made of stainless steel to minimize corrosion problems.



**Figure 1.1:** Scheme of the new engine mounting plate

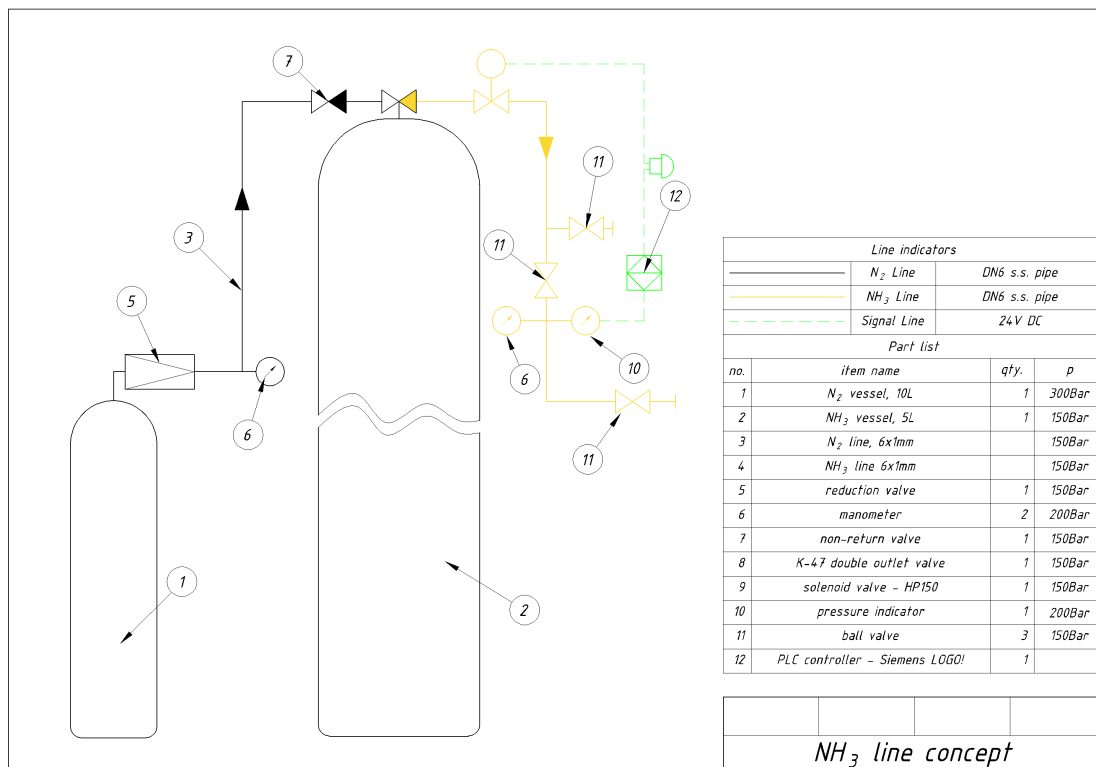
### 1.1.2 Safety Issues

For safety reasons, the entire line will be made of stainless steel components. DN4 pipe (6x1mm) made of 1.4571 steel has been selected as the base element. Such a pipe cross-section, is quite typical for high pressure hydraulic applications. It will allow good quality fittings or couplings that would be suitable for high-pressure operation, while ensuring resistance to ammonia, due to stainless steel construction. Hansa Flex's range of fasteners, which includes stainless-steel aramature variants, was selected as fasteners. Since we are still dealing with a pilot installation, it is necessary to take far-reaching safety measures. Operating in a pressurized system, is particularly dangerous when using evaporation point agents below ambient temperatures. In this case, unsealing the system can lead to intense evaporation, which is dangerous and can cause severe frostbite. To reduce the risk, an NC (normally closed) type solenoid valve will be installed on the liquid ammonia line. The use of this type of valve will also protect in the event of a power outage, and provides the possibility of using a PLC system and a safety switch. PLC system will be mainly using pressure measurement. If a drop in system pressure below a predetermined level is recorded, the system will disconnect the voltage applied to the solenoid valve.

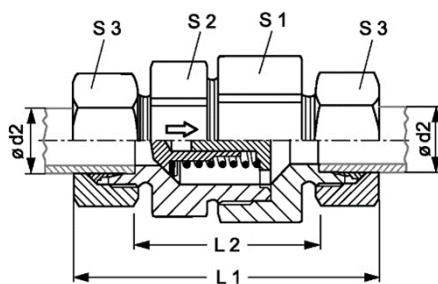
### 1.1.3 Detailed concept of the line

Detailed diagram is shown on Fig. 1.2, with signed main elements of the designed system. N2 line, will be based on existing 5L 300Bar vessel, equipped with pressure regulator 1-150Bar. At the outlet this line (near K-47 valve) a non-return valve will be mounted. In order to maintain component compatibility, the XRD-NW-06-HL valve was selected from the Hansa-Flex product range, presented on Fig. 1.3



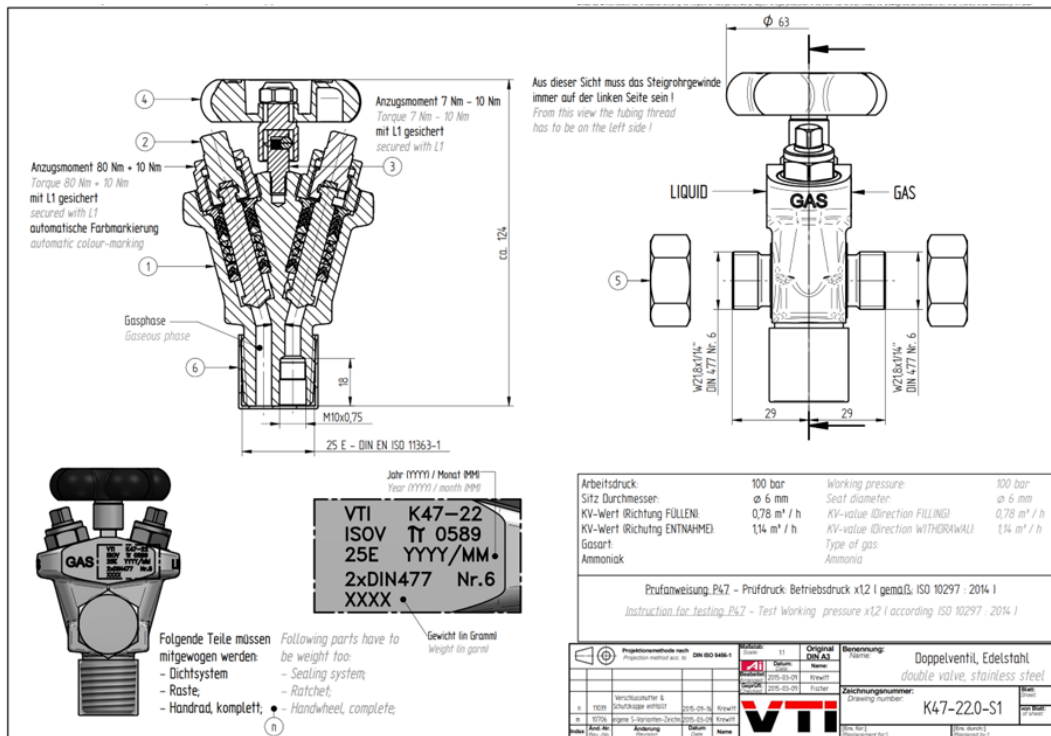


**Figure 1.2:** Diagram of the designed line



**Figure 1.3:** Half section - half view of the XRD type non-return valve

As mentioned earlier, a VTI brand K-47 dual-outlet valve was used on the ammonia cylinder (Fig. 1.4)



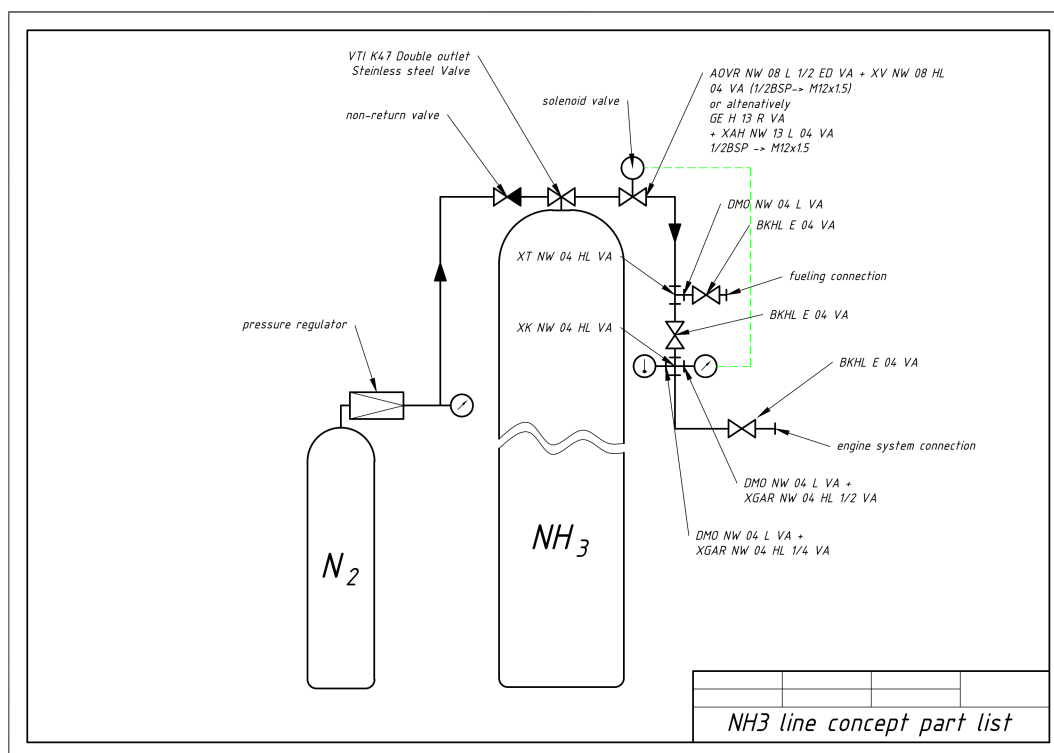
**Figure 1.4:** Scheme of the NH3 double outlet valve

The next part is the solenoid valve, to prevent pressure losses, there was need to use valve with orifice size higher than 4mm. One of the valves which fulfills this criterion, is high pressure solenoid valve HP100 produced by HPControl. Pressure transmitter is another important element of this system. As working pressure will be up to 150Bar, we chosen pressure transmitter Wika A-10. The transmitter will be connected to the PLC controller Siemens LOGO!, which is simple and reliable construction. For analog monitoring of the pressure on both lines Wika 232.30 type manometers were chosen. As NH3 vessel needs to be refueled, the installation will equipped with 3 high pressure ball valves, BKHL type produced by Hansa-Flex. All elements will be connected with use of M12x1.5 thread elements witch metal-metal sealing. This type is dedicated for DN4 pipes. Elements with different connection standards will be mounted with use of special adapters.

The current technological scheme of the ammonia line presents Fig. 1.6



**Figure 1.5:** Pressure linked devices

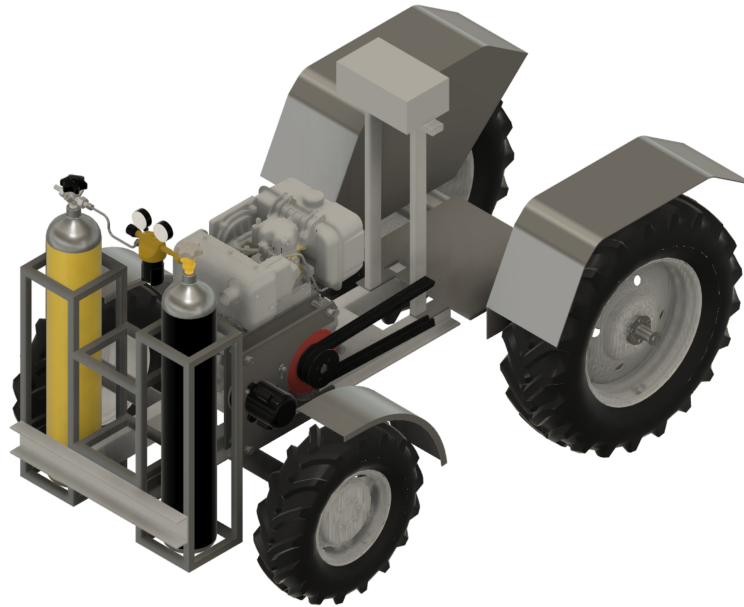


**Figure 1.6:** Scheme of the  $NH_3$  distribution line

## 1.2 Adaptation of tractor frame

The choice to mount the fuel line on the front of the tractor, was due to the weight disproportion. The standard-mounted engine was about 100kg heavier than the one currently mounted, forcing the installation of an additional load on the front. The natural place to place the line, therefore, would be this. Fig. 1.7 shows a scheme of the mounting frame for the line. At the current stage of the implementation (Fig. 1.8 of this sentence, work is underway on projecting the frame skeleton on

which the cylinders will be placed. The process of detailed layout of the individual components of the system will begin when all the elements of the system are completed.



**Figure 1.7:** View on the front of the tractor

### 1.3 Power transmission to Common Rail pump

As the basis for supplying liquid ammonia to the system to the combustion chamber, a system based on a pressure system was chosen. In this case, the need for a high-pressure pump to compress the ammonia was eliminated. This allowed the system to be simplified as much as possible, which greatly affects safety by reducing connections and moving parts. As the engine will require a pilot dose of bio-diesel to operate correctly, it is necessary to design a transmission system from the engine shaft to the fuel pump shaft. In order to ensure easy repair in the event of failure, or this change in transmission ratio, it was decided to use a standard toothed belt solution. According to the available belt systems, ST8 was chosen as the most common. It also gives the opportunity to achieve a gear ratio of 2:1, which was used in the adaptation of a similar system on the engine dyno test rig. ECU used in this system requires information about shaft position and information about the common rail pump. As there is not enough space to use classic encoders, we decided to use signal wheel set with inductive indicators to determine position of the shafts. Signal wheels dimension presents Fig. 1.9.

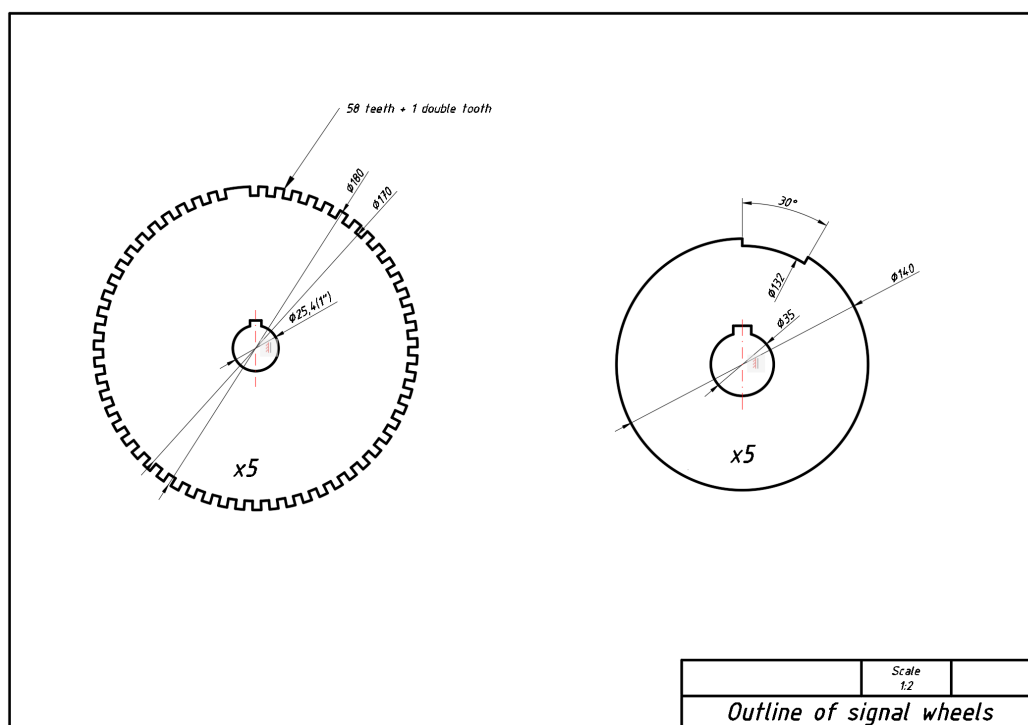


(a)

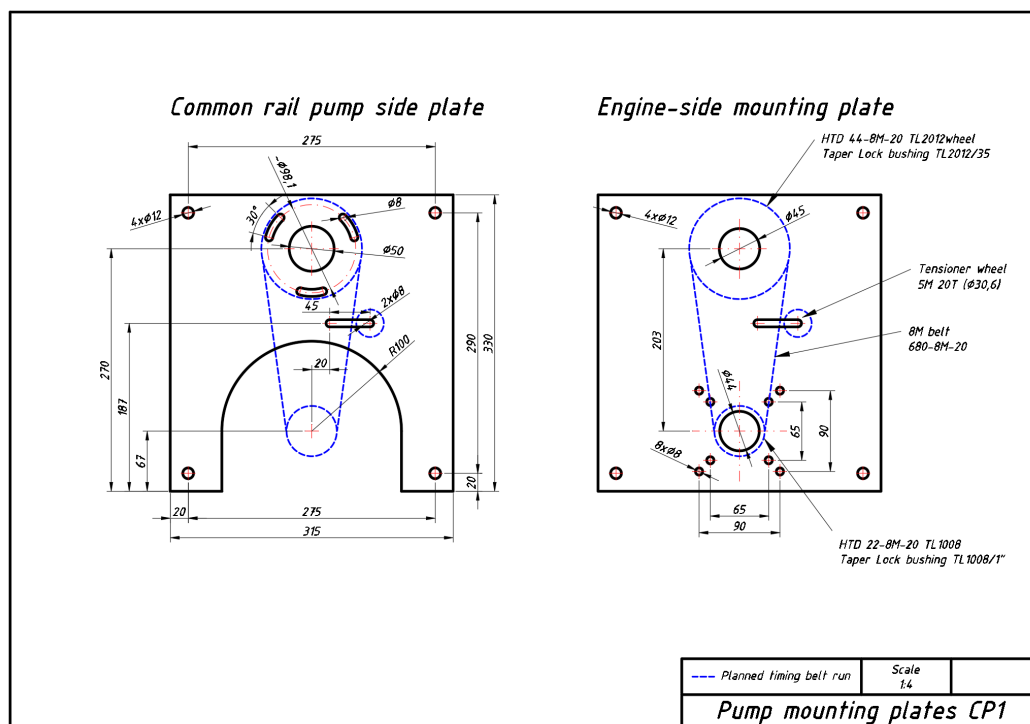


(b)

**Figure 1.8:** Progress in frame modification (a) electronic accelerator pedal mounting, (b) disassembled frame



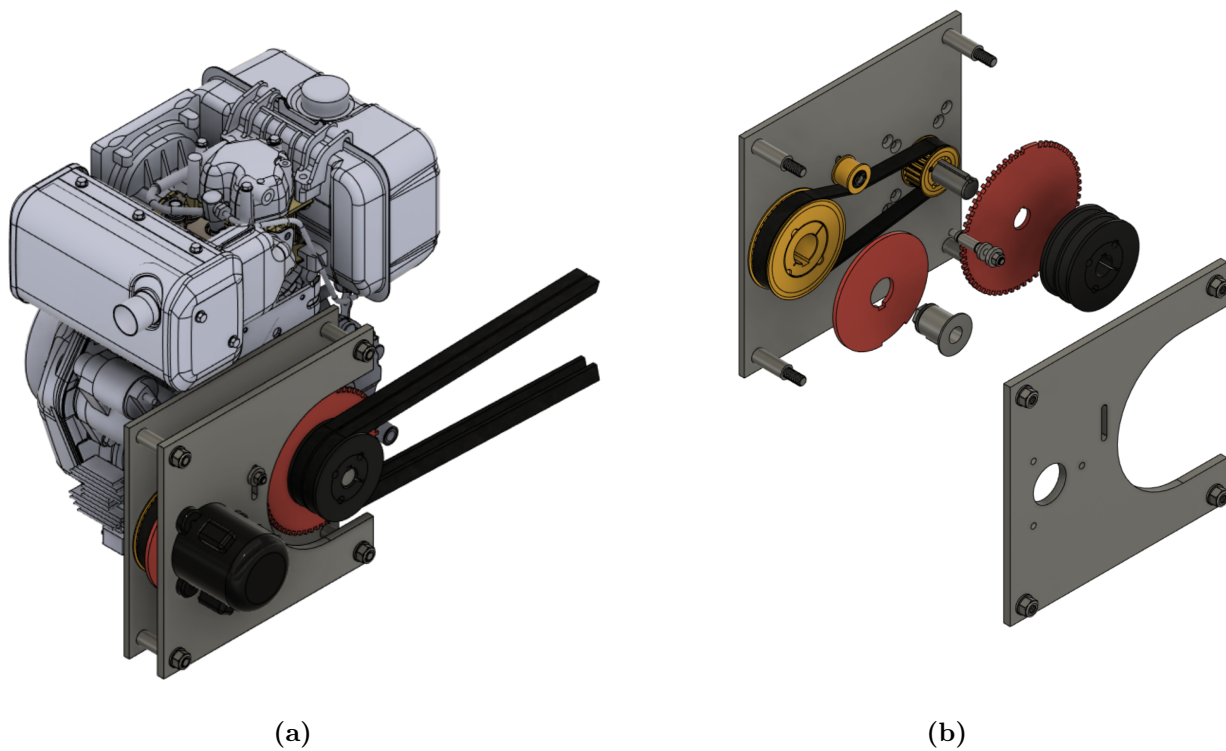
**Figure 1.9:** Signal wheel dimensions



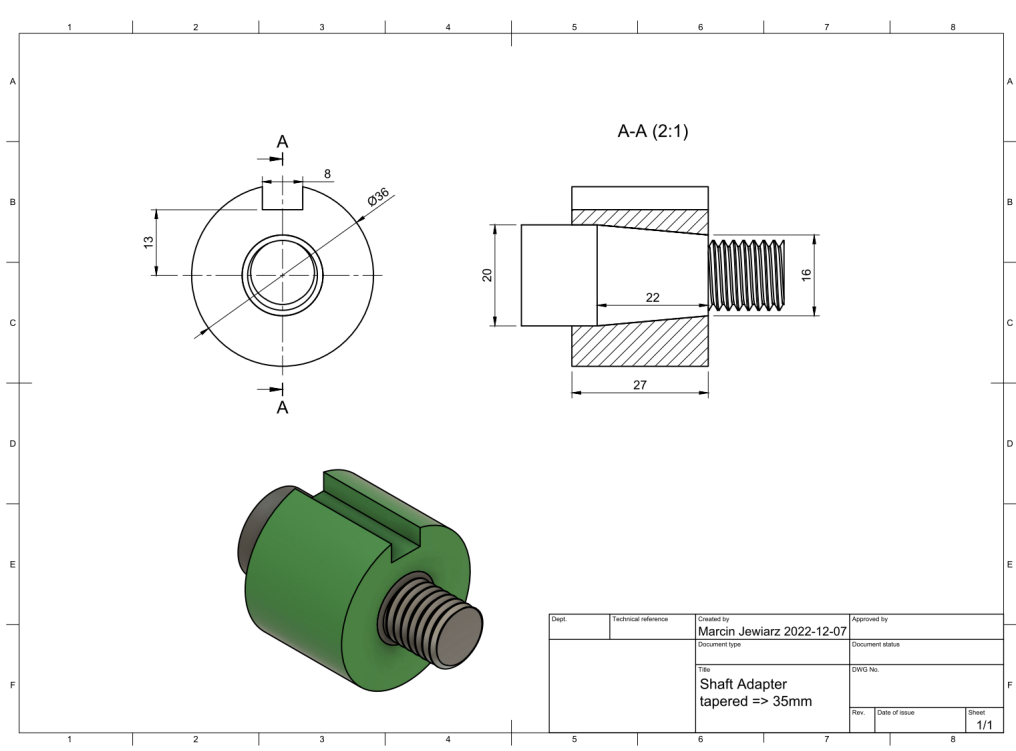
**Figure 1.10:** Overview of the mounting plates

Since the shaft of the Common-Rail pump is tapered, it became necessary to make a suitable adapter. After market analysis, a shaft diameter of 35mm was selected. The target adapter is shown in the figure. The adapter allows the insertion of a standard Taper-Lock bushing, on which the corresponding pulley will be mounted. The completed power transmission system assembled is shown on





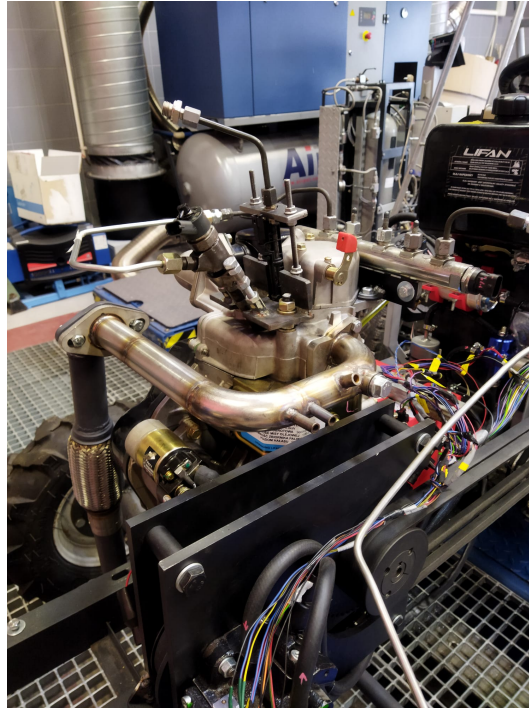
**Figure 1.11:** Overview of the of the power transmission system designed for CR pump. (a) system overview, (b) detailed exploded view



**Figure 1.12:** Pump shaft adapter from taper to 35mm connection

Typically on agricultural tractors, the exhaust is discharged through a muffler mounted in front of the driver's cab. In the case of this tractor, it was decided to place the exhaust behind the driver's cab at the bottom of the tractor for operator safety reasons. In this case, it was necessary to design and build a new exhaust route. In addition, a new exhaust manifold was retrofitted to accommodate additional measuring devices as required. The entire system was made of stainless steel to ensure adequate resistance to corrosion caused by ammonia. The entire exhaust system is shown in figure 1.13

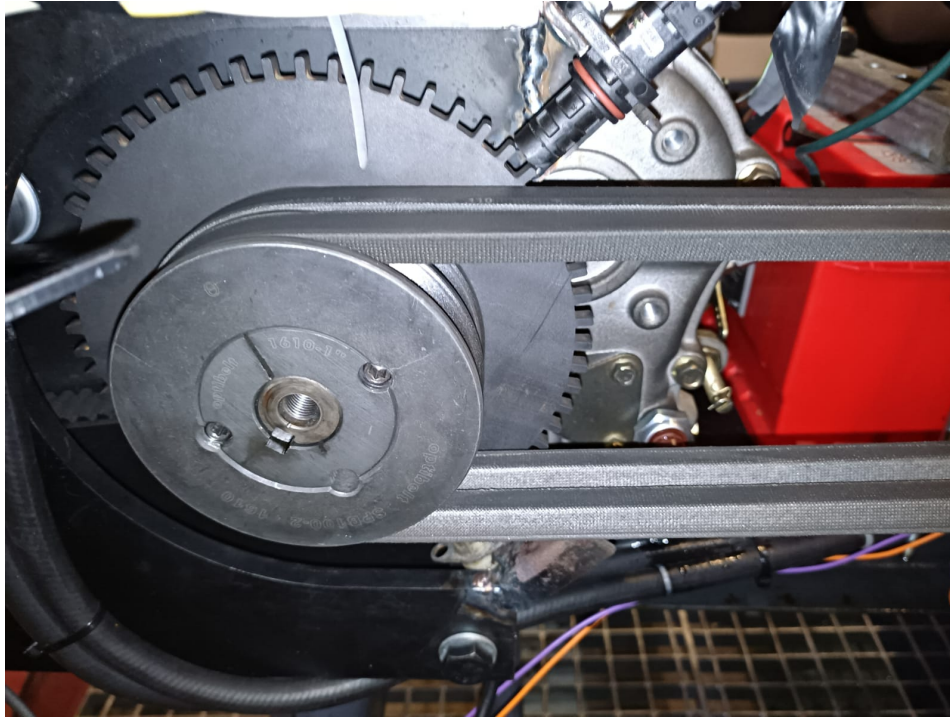




**Figure 1.13:** Overview of the new exhaust line

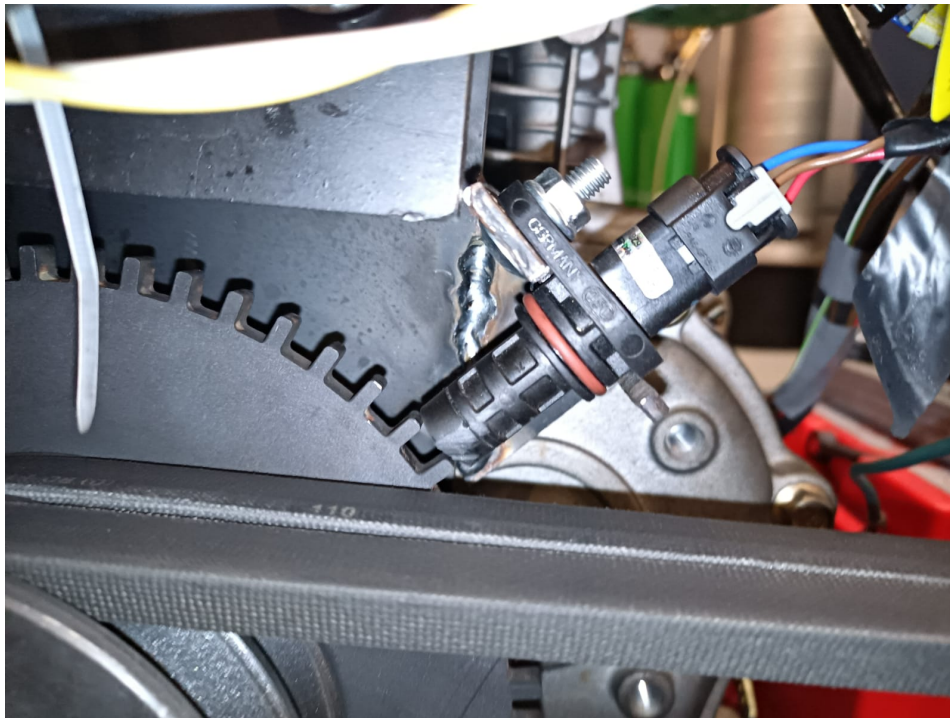
## 2 Adaptation of the PCA2000 indication system to the tractor

The measurement system has been utilized previously within the project, however that was within the confines of the stationary engine test rig. The new setup had to be built with available parts and made to work without the angular encoder present in the previous test rig.



**Figure 2.1:** The 60-2 teeth wheel used for crank-angle measurement.

The most important task therefore was the provision of an adequate shaft angle measurement system compatible with the working tractor. The vehicle itself contains two possible measurement sources for this purpose, that being the double gap wheel mounted to the camshaft and the tooth wheel with 60 nominal teeth (with a two teeth marker gap) mounted on the crankshaft. Both of these devices are equipped with Hall Effect sensors which supply a signal to the injection controllers. The camshaft wheel due to its design could only be used as the phase reference for the system. As the system allows for a phase reference based on the pressure signal, the corresponding sensor was not connected to the PCA2000. It was decided to fully rely on the pressure signal, and the signal from the crankshaft wheel.



**Figure 2.2:** The hall sensor used by the injection controllers.

The use of the crankshaft wheel has led to certain unforeseen challenges with engine-measurement system synchronisation. In the first attempt, as per the instruction manual the Hall-Effect sensor used by the injection controllers was connected to the Hall Sensor pins on the PCA2000. This approach was found to be unsuccessful for two reasons:

- signal interference from the injection controllers,
- phase reference being located during the combustion phase.

The first issue was partially mitigated by subsequent connection of all sensor and inputs to the PCA in star-ground configuration to the negative battery terminal of the tractor. This was preceded by a thorough tracing of the system connections, and ensuring that the ground connections are as per the manufacturers specifications. The second problem however was impossible to mitigate despite the authors efforts and help from the system manufacturer. It was found, that as the system is designed to run in real time, pressure measurement signals are sampled based on the angle sensor signals. The two tooth gap used for reference corresponds to the loss of  $12^\circ$  from the pressure signal, and the built in interpolation algorithms were not able to deal with this issue. As the combustion phase is of high importance to the measurement, this led to highly erroneous readings and to misidentification of the crank phase by the system.

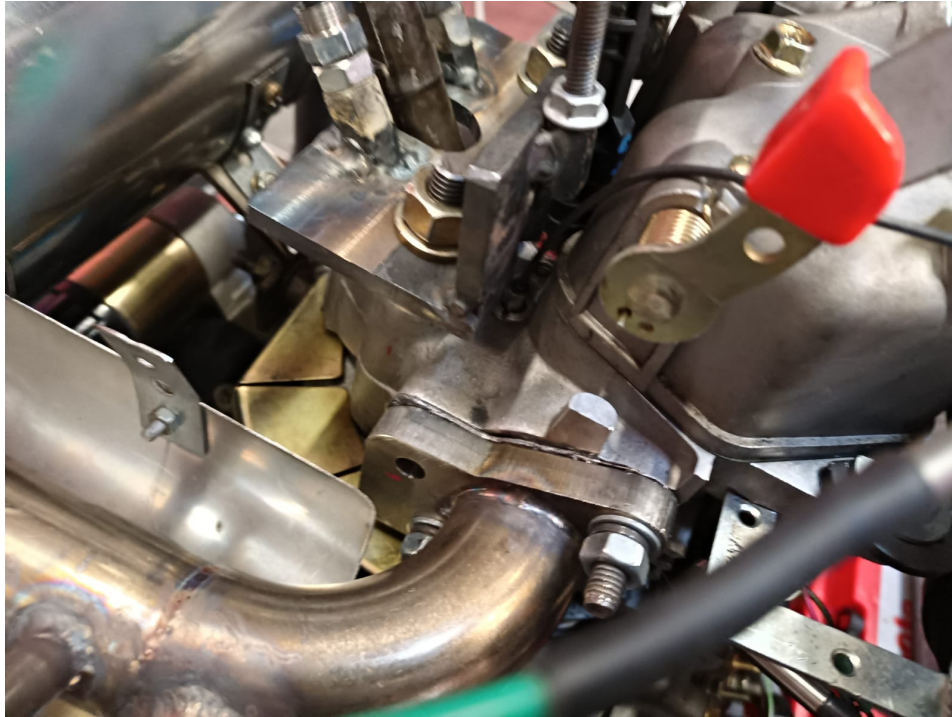
The aforementioned problems were further mitigated by the use of a separate position sensor. The new sensor was of the variable-reluctance ("VR") type, and a separate mount was constructed for it, locating the pass of the marker gap during the early compression phase. It should be noted, that locating the gap during intake or exhaust is not possible on a crankshaft signal wheel. This setup also reduced signal interference. Unfortunately, a pressure error is still present during the marker pass, however due to its location it has a lesser influence on the overall analysis.



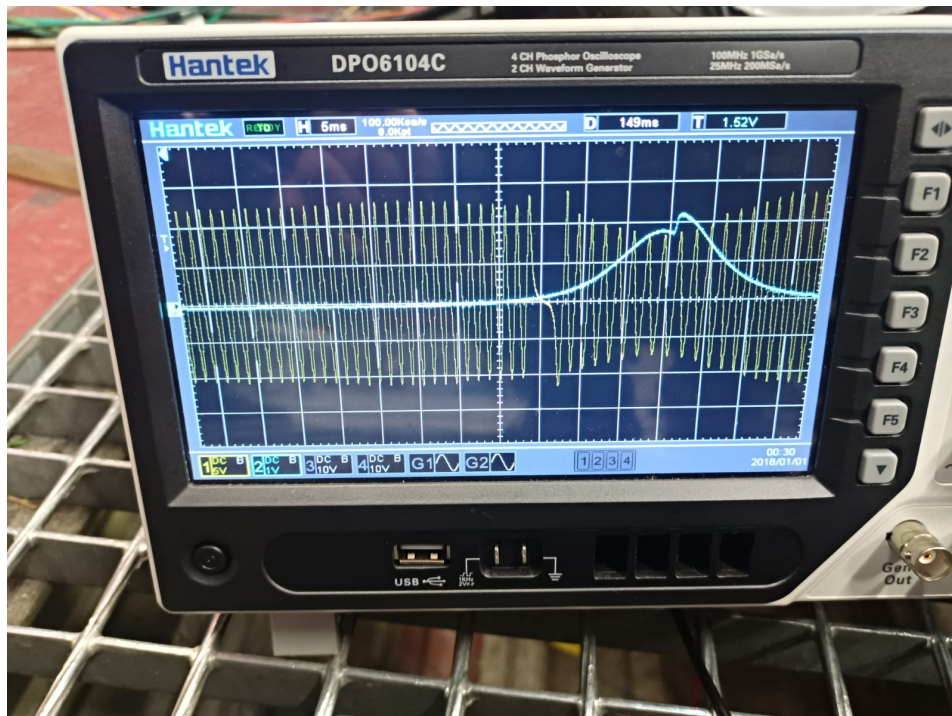
**Figure 2.3:** The VR sensor in its final location.

In the new sensor setup an additional problem was found - a distortion of the trigger signal as read by the PCA just after the marker event. This was mitigated by software setting where the "divisions" value in the trigger setup was shortened for the last pulse and elongated for the first pulse. The "divisions" correspond to the angular distance corresponding to a single sensor signal pulse. The fact that the signals are produced correctly has been verified by the use of an oscilloscope. The view from the oscilloscope is shown in fig 2.4.





**Figure 2.5:** Pressure sensor location on the tractor indication rig.



**Figure 2.4:** Oscilloscope signal traces; blue - pressure signal, yellow - VR sensor signal.

The in-cylinder pressure signal was sourced from a differential sensor, manufactured by Kistler and the signal was amplified using a dedicated charge amplifier.

### 3 Final Assembly of the tractor elements

To ensure an adequate level of safety in the operation of a liquid ammonia-fueled system, it is necessary to use an appropriate system for monitoring the operating parameters of the entire tractor. For this purpose, a parameter recorder was used, which also can control selected devices, in particular solenoid valves. The task of such a system, in addition to traditional monitoring of engine operation (engine rpm, exhaust temperature) and the tractor (wheel speed), should monitor the pressure in the liquid ammonia system. If a large leak is detected, resulting in a sudden drop in system pressure, a suitably prepared algorithm will activate a solenoid valve at the beginning of the liquid ammonia line. The control panel of the device makes it possible not only to view the operating parameters and the status of the solenoid valve but also to change the operating pressure of the line (in the case of changing the pressure on the regulator, the change must be made manually) and the values at which the emergency shutdown of ammonia will be initiated. In addition, the system used offers the possibility of using other devices, such as an ammonia concentration sensor, which could also be used in the case of smaller leaks. The ready-for-operation control panel presents Figure ??



**Figure 3.1:** View of the control panel with most important tractor and engine parameters

The final step was to adapt the tractor housing to the new systems. A new bonnet was made, the purpose of which is to protect against accidental access to moving parts as well as damage to protruding elements, such as sensors or injectors. Due to the modular nature of the hood, it is possible to make it both in transparent material (polycarbonate) and, for example, perforated sheet metal (to provide access to cooling air). To provide adequate protection for the driver, it was decided to use a suitable windshield made of polycarbonate. In addition, elements of the plating were equipped with promotional elements of the project. All shell components are removable so that there is the possibility of modifications to the engine or other components (Figure 3.2).

To sum up. The tractor has been prepared for testing. The engine has been retrofitted with all the necessary extras to allow the engine to run on liquid ammonia. The unit can be handed over for further activities related to the calibration of the engine to run on the new fuel.



(a)



(b)

**Figure 3.2:** overview of the tractor with wheel guards and operator's cab in place (a) and fuel line in place (b).