

## Innovative Mechatronic Solutions For Decoupling In Agricultural Machinery

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The use of certain agricultural machines equipped with parts driven by the power take off (p.t.o.), exposes the operators to the risk of catching and dragging, with dire consequences in case of accidents, which in most cases result in fatal injuries. Especially the round balers, chippers and the manure spreaders does not have, to date, effective ways to reduce these specific risks.

The solutions available on the machine are numerous, but not resolute and focused on the systems that are exclusively effective to protect the machine kinematic chain by any breakages. Infact, the torque levels reached for the actuation, are significantly higher than those needed to harm operators.

In previous experiments, the research unit of the Florence University, had studied effective systems for decoupling of the transmission. These studies showed that to make effective a decoupler device was necessary to have an active safety, namely to ensure in rest conditions the transmission interruption.

For these reasons, within the Promosic project, the Research Unit of Florence (UR-UniFi) based on their experiences, the device, represented by the electromagnetic clutch, has employed, as the only system capable of offering an active safety, replacing, however, the inefficient control system with two types of innovative sensors, which monitors the human presence, through detection of respiratory activity, or body temperature.

The innovative aspect of this research is the implementation of a control device coupled to the electromagnetic clutch. An infrared device, with laboratory tests performed, was effectively applied on round balers and shredders machines. The tests performed by interposing the human limbs inside the sensor monitoring field, showed response times of 50 ns to 0.4 m distance.

The results have shown the high potential of the developed system for transmission decoupling. Furthermore, its cheapness, makes it a feasible solution for every the agricultural machinery manufacturers to meet the requirements imposed by current safety regulation

Keywords: Safety of agricultural machines, decoupling devices, innovative monitoring sensors

### 1. Introduction

Fatal accidents occur every year to farmers due to the failure of the machinery to disconnect the motion transmission devices, when the operator comes into accidental contact with moving parts (Miceli *et al.*, 2010). These accidents occur in different types of agricultural machinery, but in particular with round balers (Grisso *et al.*, 2013), when the operator must remove clogged material from the feeding zone. However, high risk of injury is common in other machines such as manure spreaders and wood chippers due to different operational characteristics.

Over the years many solutions were proposed, but none decisive as they all focused on the activation of a mechanical driven decoupler by means of a levers and cables system, or after exceeding a torque threshold. These systems allow to stop the movement between the conductive element and the conduit element when the torque exceeds the predetermined maximum value, therefore, they are only effective in protecting the

kinematic chain from failure (Vieri and Laurendi, 2003b)". The torque levels for their activation are significantly higher than those required to avoid harm to the operators. For example, in the round balers case, the only safety element for operator protection that approaches the power supply area of the machine, is represented by the safety bar on the feed mouth. This device keeps the subject at a distance so as to prevent accidental contact by the collector roller when carrying out maintenance operations or when approaching the front of the vehicle but is unable to prevent voluntary contact when it is intended to unlock the machine.

The Research Unit of Florence (UR-UniFi) has been studying this problem for several years, defining the criteria needed for the device creation, capable of reducing the dragging risk on the motion transmitting organs. The studies highlighted that to make the decoupling device effective there must be an active safety mechanism which ensures that the transmission is interrupted when the machine is idling (Vieri and Laurendi, 2003a), (Vieri *et al.*, 2000).

Based on this principle, the UR-UniFi has developed a system which interrupts the torque transfer between the working parts via an electromagnetic clutch.

The system consists of 5 essential elements: the driving shaft, the driven shaft, two clutch discs and the coil to create the magnetic field. The driving shaft attached by couplings to the power take-off (p.t.o.) is bound to the traction disc by the electromagnetic clutch and to a cylindrical axle on which the bearings that support the driven shaft are assembled. The system is monitored by optical sensors to create a control barrier around the dangerous zones of the machinery. Following numerous tests the device proved effective. The only problems related to its efficacy revolve around the control system run via optical sensors.

Based on these assumptions, UR-UniFi, within the Promosic Project, concluded the use of the electromagnetic clutch as being the only system capable of offering an active safety mechanism, while replacing the original inefficient control system with two types of innovative sensors able to monitor human presence: one through the detection of respiratory activity and the other through body temperature.

## 2. Design and methods

In past trials the Research Unit performed laboratory experiments on the electromagnetic clutch in order to detect the functional features effective in stopping the torque transmission acting on the working parts of agricultural machinery. These tests were conducted in collaboration with the IMAMOTER – CNR – National Research Council (Institute for Agricultural and Earthmoving Machines, coordinated by Dr. Eugenio Cavallo).

Primarily, the functional tests aimed at determining:

- The maximum transmitted torque values (Nm);
- The system defusing times (ms).

The laboratory experiments were carried out at the test facilities of IMAMOTER – CNR in Candiolo (Turin). In the test scenario, the clutch was connected to a support to keep it locked in order to simulate the set up on a tractor. The electromagnetic clutch operation was powered by the tractor's battery. The clutch, if not reapplied is normally disconnected. Thus, the coupling between the two discs takes place when the coil is energized. The input torque (engine) to the clutch is delivered by the tractor's power take-off (73.55 kW). The p.t.o. speed was set to 540 revolutions per minute (rpm). The resistant torque was produced by an electromagnetic brake. The resistant torque modulation was achieved by a brake control system.

In order to measure the number of turns, the transmitted torques and the coupling times, the system was set up as shown below:

Interposed between the tractor and the clutch:

- torquemeter
- rev counter
- data acquisition system for recording the driving torque and rpm output from p.t.o.. The data acquisitions were performed with a frequency of 500 Hz.

Inserted between the clutch and the brake dynamometer:

- torque meter
- rev counter
- control and recording system of the resistant torque and rpm input to the brake dynamometer

The effectiveness of the system was verified by performing two series of tests. In order to reproduce the critical steps that lead to the interruption of the transmission, the first test determined the maximum transmissible torque testing the clutch's limit when the two disks slip. During the test, the transmitted torque and the revolutions per minute were recorded with voltage values of 12 V upstream of the clutch. The maximum transmittable torque was monitored by progressively increasing the resistance of the brake dynamometer up to the point of slipping which was evident by the absence of the motion transmission and by the noise made by the clutch itself. The tests were performed in three replicas to obtain significant data.

Before proceeding to determine the maximum torque tests, the monitoring of the clutch temperatures, by means of a thermocouple, was carried out. The values were then compared with those during the activation phase to evaluate any differences in case of overheating.

The second series of tests were designed to determine the decoupling times of the clutch discs when power to the coil is interrupted. This interruption simulates the one induced by the external safety control system. In this case, the decoupling time was calculated indirectly considering the interval of time taken between the maximum torque transmittable state and the standard rotation speed in the disengaged state.



Figure 1 – Setting up for the tests on the electromagnetic clutch



Figure 2 – Data Acquisition System for the clutch (connected to laptop), monitored upstream, and for the brake dynamometer control

Following these experiments, the project activities focused on the identification of sensors capable of detecting human presence and generating a signal which controls the decoupler to cause the automatic disengagement of the transmission. In an initial phase of the study, a device called "Vital Radar" (Adib *et al.*, 2015) was identified. It consists of two main components:

- a pair of radio antennas - able to detect signs of ribcage movement
- a supporting electronic device - to supply power, transmit and receive and generate analog or digital output signals (Figure 3).

Subsequently, another detection prototype was implemented using passive type infrared sensors (Saponara *et al.*, 2016). The device consisted of a pulse light laser-emitting diode that produces an infrared beam. In a photodiode detection system the beam passes through a lens and generates a 60° cone at 2 m. The operating principle is based on measuring the interval of time between the emission of an infrared beam and its reception resulting from the beam hitting an obstacle. To remove any interference during measurements, a microcontroller with a self-calibration system to compensate for disturbances related to the environmental temperature and to the loss-response over time was installed.

The device was able to convert the energy detected into a measurable electrical signal (Figures 4, 5).

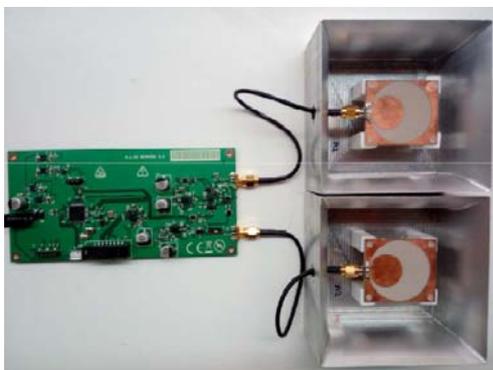


Figure 3 – Sensor "Vital Radar" for the monitoring of respiratory activity

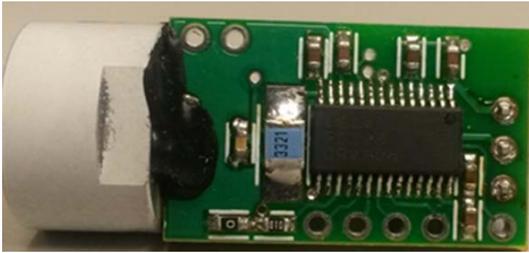


Figure 4 – Infrared sensor

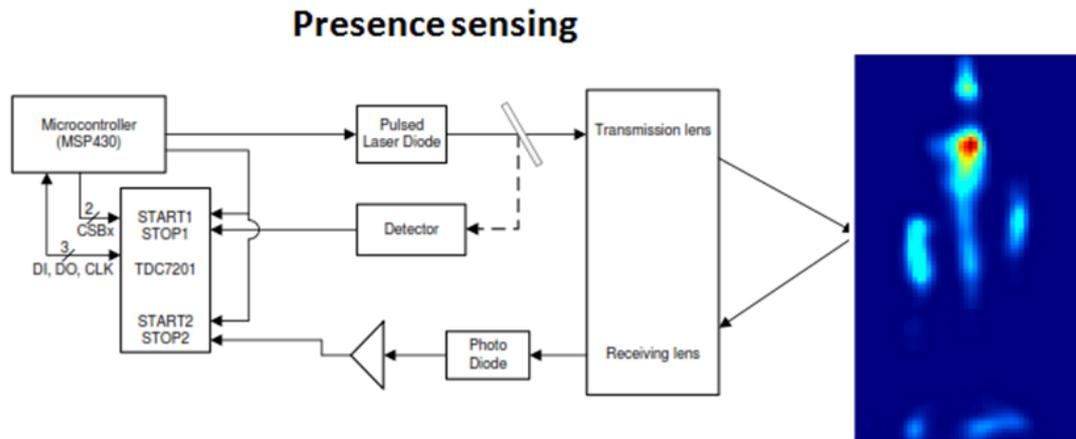


Figure 5 – Operation scheme

### 3. Results

The maximum transmittable torque at 12 V is equal to  $1000 \pm 12$  Nm. The clutch manufacturer indicates 780 Nm as torque limit. If these torque values are exceeded, slip phenomena with the consequent instability of the system occur (Figure 6). Therefore, the times tests were operated at 750 Nm capacity to ensure the continuity of the transmitted torque.

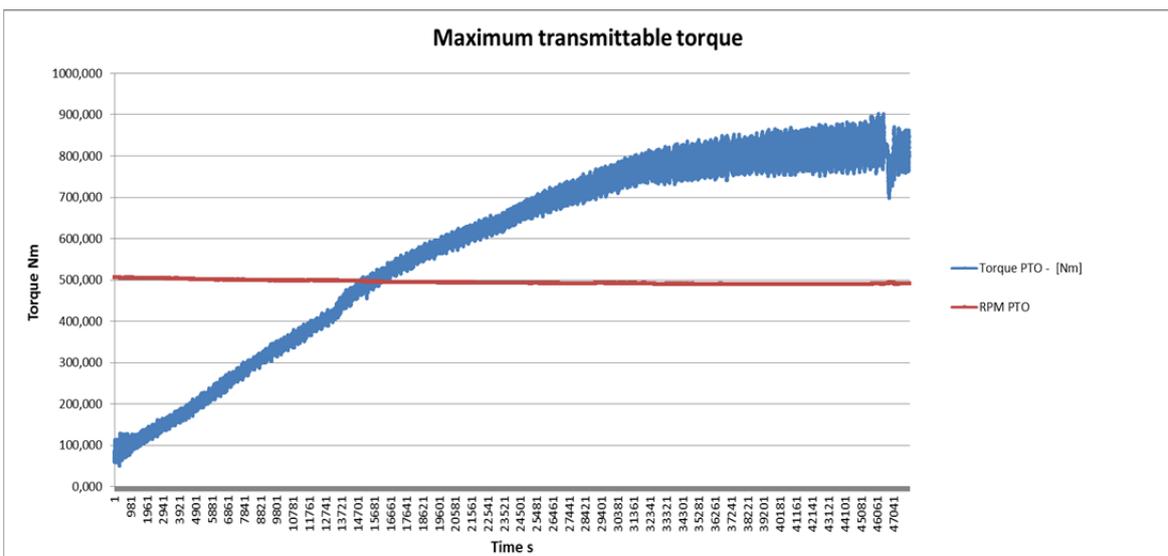


Figure 6 - Third Test for the Evaluation of Maximum Transmission Torque

Figure 7 shows an example of an experiment relating to the stopping time of the torque transmission following the power interruption to the electromagnetic clutch. The results of the various tests indicate an average value of 140 ms to pass from the condition of  $742 \pm 30.11$  to 0 Nm. As for the variations of temperature, it shifted from a value of  $37^\circ\text{C}$  to the value of  $45.5^\circ\text{C}$ , after the device was activated.

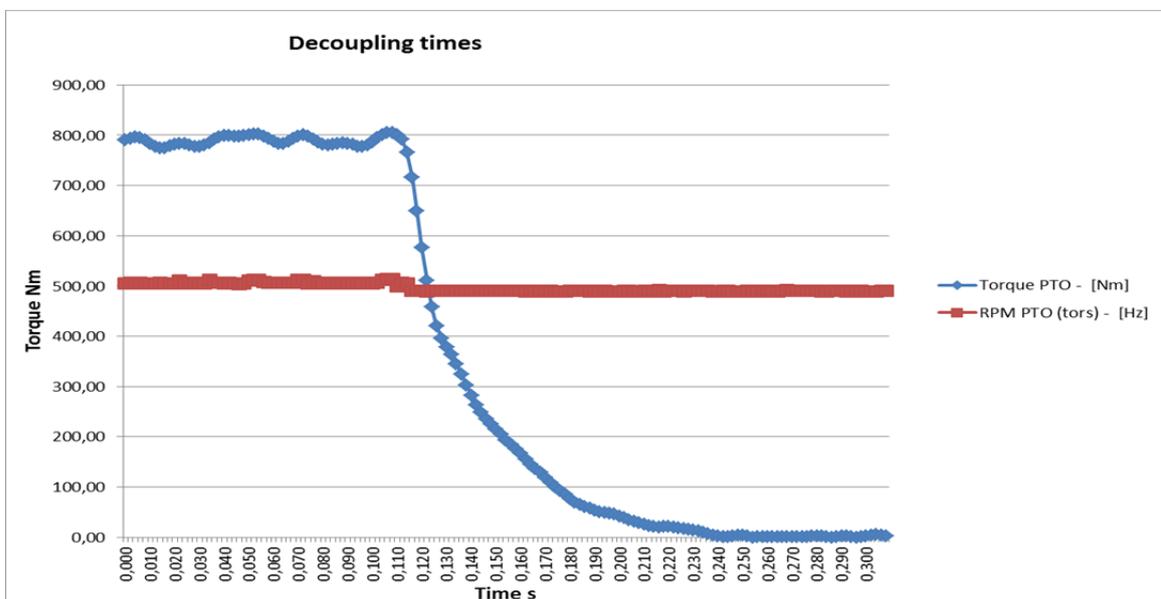


Figure 7 – Third evaluation test for decoupling times

Regarding future development of the human detection devices in the danger zones of machinery, the first initiative, targeting monitoring of respiratory activity, has been temporarily postponed. While achieving good results during laboratory testing it was concluded as difficult to implement in an agricultural environment due to high design and installation costs.

Based on the laboratory tests carried out, the second solution involving the infrared device was found to be extremely effective in round balers and wood chippers. The tests performed by interrupting the sensor monitoring field with human interaction showed response times of 50 ns to 0.4 m distance.

Respectively, suggested solutions for the positioning of the control device on the understudy machines were assumed. In regard to round balers, the following possibilities were identified:

- positioning of the sensor in the tractor rear. A simpler hypothesis that proves more suitable for the adjustment of older machine models;
- positioning of the sensor on the round baler itself. In this case, for efficient detection the sensor must be installed on a bracket positioned laterally to the machine power take off point.

As for wood chippers, the sensor can be efficiently placed over the feed opening.



Figure 8 – Example of decoupler application on wood chippers

#### 4. Discussion

The laboratory test results on the electromagnetic clutch highlight the reliability of the device as it immediately and automatically stops the transmission of motion by providing an active type protection.

The transmission can be restored only if the causes that have led to the critical shutdown have been removed and by the operator's consensus. Therefore, the security system is difficult to tamper.

This system represents an effective safety device that can be directly integrated by manufacturers on agricultural machinery models and can also be considered a valid solution to adapt the machines in use.

However, more system validation is required in the field, applied to the various agricultural machines. In this regard, in previous studies, the device was tested in field on round balers with satisfactory results. In this project field tests were carried out, in collaboration with the research unit of Viterbo, on wood chippers.

In such preliminary tests, the proper functioning of the decoupler is detected in realizing transmission interruption. The device efficiency must be assessed in conjunction with the control system, in the field conditions.

The innovative aspect of the device is related to the use of state-of-the-art sensors for the detection of the operator. In an initial phase of the study, a device called "Vital Radar" was identified, subsequently, an infrared device, with laboratory tests performed, was effectively applied on agricultural machines.

The tests performed by interposing the human limbs inside the sensor monitoring field, showed response times of 50 ns to 0.4 m distance. Laboratory tests have shown significant results for both of the control devices analyzed. However, the infrared sensor showed a greater reliability with the monitoring and has lower design and implementation costs.

A very important aspect is the sensors positioning on the machine, so that the system can work properly. For these reasons, some hypotheses have been proposed, with reference to the round balers and the wood chippers that have a different operating mode and consequently the dangers are different.

Further studies on the reliability of the detection system, in particular aiming at defining the critical issues encountered in the operational activities in the field are needed.

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