A Device for the automation of the engagement between tractor's power-take-off and PTO-drive shaft

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Abstract
Manually connecting and disconnecting the PTO-drive-shaft to the tractor's PTO are difficult operations, often executed in narrow spaces between tractor and operating machine and represent a source of risk of accidents. The automation of such operations would significantly contribute to improve the ergonomics in agricultural work. At a time, risks of accident would decrease as a consequence of the reduction of manual interventions.
This paper describes a device developed by MR-Industria Meccanica s.r.l., aimed at significantly reducing manual interventions during the connection/disconnection of the PTO-drive-shaft to the tractor's PTO, reporting the results of tests conducted at CRA-Ing.
Although it has been proposed in 2002, the device is still of interest for the sectors of assistive technology, ergonomics and safety and probably deserves more attention and diffusion.

Keywords: automation, PTO-drive-shaft engagement.

Introduction
In the continuous updating of the components of agricultural tractors, the ergonomic aspects of the engagement of the PTO-drive shaft to the tractor's PTO became subject of a study that provided a device aimed at the automation of such operation.

Usually, the PTO-drive shaft is manually connected to the PTO with the operating machine mounted on the three point linkage. The narrow space in which the operation is executed determines discomfort and fatigue conditions for the operator that, at the same time, must lift and correctly place the drive-shaft on the PTO and push it until the connection occurs. This aspect is associated to the risk of accidents that could occur, mostly in field, during works requiring frequent engagements and disengagements of the PTO-drive shaft.

The impact of these aspects can be limited by reducing manual interventions. On purpose, a device has been developed and patented by MR-Industria Meccanica s.r.l. (Montone, PG, Italy) that allows to automatically execute most of connecting and disconnecting procedure.

This paper reports a description of the device and of its working mode and the results of some tests made with the aim of verifying its reliability and estimating the effects on the reduction of fatigue and discomfort. In the following it will be called MR-device.

Purpose
With the aim of substantially reducing manual interventions in the engagement and disengagement of the PTO-drive shaft with the tractor's PTO, the device has been designed as a frame independent from the PTO power transmission and, at the same time, for resisting to traction solicitations that would have the effect of extracting the drive-shaft power-input-connection (PIC) from the PTO tang during the work. By changing the shape and dimensions

of the steel plate supporting the standard elements of the mechanism, it can be mounted theoretically in all tractor models.

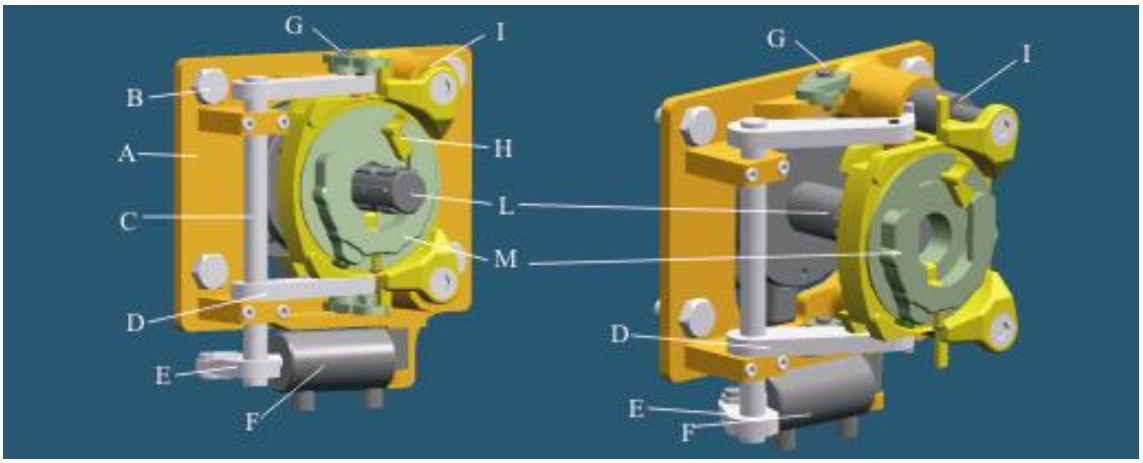

Figure1. Sketches of the MR-device closed (left) and open (right), without PTO-drive shaft. A) support plate; B) fixing bolt; C) drive pivot; D) drive lever; E) drive crank; F) hydraulic cylinder; G) locking levers; H) wing-nut that lock the drive-shaft; I) telescopic guide bearings; L) PTO tang; M) PTO-drive shaft U-bracket

Description

The fig. 1 shows a sketch of the MR-device and of its main components. It consists of a steel plate supporting the mechanism that is driven by the tractor's hydraulic system and electronically controlled. After having installed the device on the tractor, the only manual operation required in connecting and disconnecting the PTO-drive shaft to the PTO is to insert the drive shaft PIC in the dedicated bracket of the device when it is in open position. The engagement or disengagement between the PTO tang and the PIC is hydraulically operated and occurs respectively by forward and backward sliding of the bracket. Because of its reduced dimensions (width: 225 mm; height: 290 mm; length: 95 mm), it can be lodged inside the frame surrounding the taw-hook that works as partial protection of the PTO (fig.2).

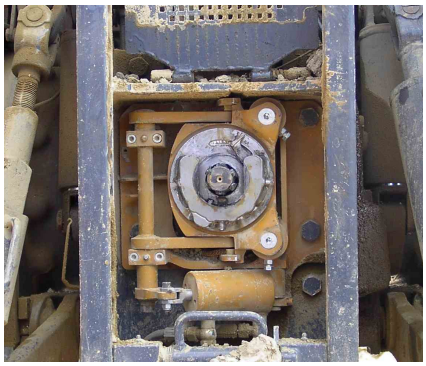

Figure 2. The MR-device mounted on a tractor

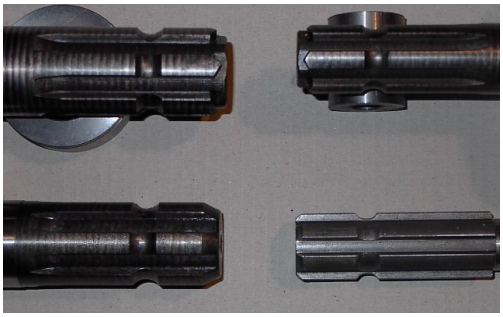

Figure 3. Original PTO tangs (below) and modified PTO tangs (above), 15 mm longer than the former, showing teeth with V-splayed edges

PTO tang and PTO drive-shaft PIC

The use of the MR-device requires a suitable PTO tang (provided by the manufacturer) 15 mm longer than the normal tang. The teeth of the modified tang have a V-splayed edge (fig. 3) facilitating the engagement of the similarly shaped teeth of the drive-shaft PIC (fig. 3). In order to reduce the friction and the cases of jam (that could occur when the apices of the teeth of the tang and of the drive-shaft PIC are perfectly in line, obstructing the drive shaft PIC sliding forward), some tang's teeth are slightly longer (for instance, in the six teeth tangs, two teeth are 3 mm longer than the others). Beyond the V-splayed PIC teeth, the drive-shaft must be modified as shown in fig. 4, in order to be lodged in the U-bracket of fig.1.

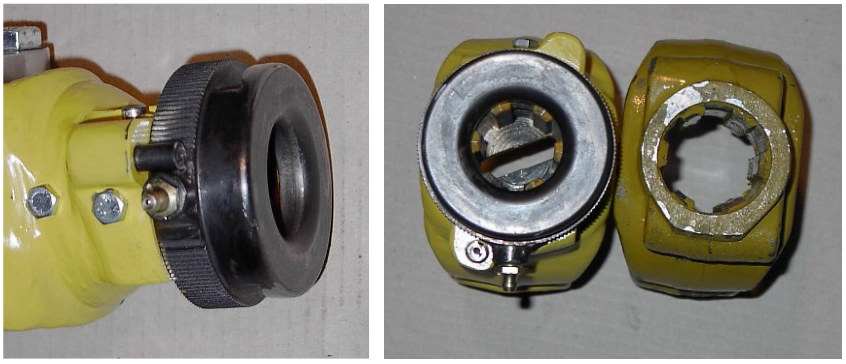

Figure 4. The PTO-drive shaft PIC presents a steel locknut shaped for being inserted in the U-bracket, as the teeth edges are V-splayed, like the tang teeth

Hydraulic system

The forward/backward sliding of the bracket along the PTO axis is operated by the action of a double effect hydraulic cylinder on a lever system. The cylinder is fed by the low-pressure hydraulic circuit of the tractor, through a two-ways electro-valve activated from the control board and directly connected to the tractor's electro-valve controlling the PTO, so that the engagement/disengagement can be executed only when the PTO is steady.

Figure 5. Control board on the cab of the tractor. G: green signal indicating the PTO-drive shaft engagement; R: red signal for the disengagement; J: joystick controlling the electro-hydraulic system; S: alarm turn-off

Electric system

The goal of the electric system is to manage the interventions of the electro-valve that controls the hydraulic cylinder depending on the signals sent by the sensors indicating the open / closed position of the device and the state of the PTO (rotating or steady). The control board is installed on the cab (Fig. 5) and presents a joystick controlling the engagement (green signal) and the disengagement (red signal). These operations can also be

executed from outside by means of two buttons on the rear fender of the tractor. Moreover, in order to reduce the risk of accidents, the system is capable to combine the signal of the position of the device with the sensor revealing the presence of the driver on the seat.

MR-device working way

The first operation, after its mounting on the tractor, is the manual connection of the PTO-drive shaft. The PTO must be off and the device must be in its open position. The connection foresees the following steps (fig. 6)

- The U-bracket on the device must be rotated until it locks in vertical position (concavity upward, figs. 6-a and 6-b);
- After having lifted the free end of the PTO-drive shaft, the locknut must be rotated as well until the grooves are in vertical position, so that they can be introduced in the U-bracket (figs. 6-c and 6-d);
- The locknut must be pushed downward until the wing-nut lock is on.

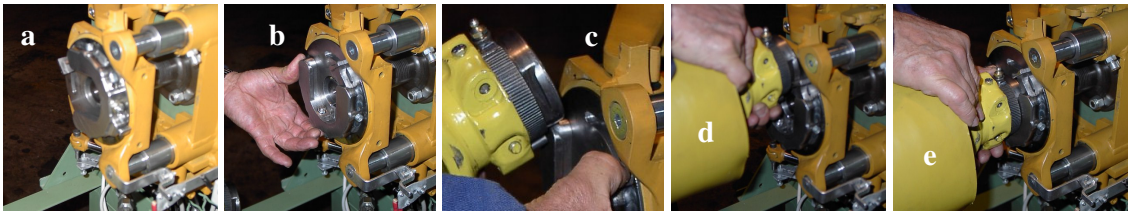

Figure 6. Operation sequence of the manual phase of the connection of the PTO-drive shaft to the MR-device

The manual phase is now concluded: the actual engagement between the drive-shaft and the PTO is operated by the electro-hydraulic mechanism controlled by means of the buttons described above. After the engagement, the PTO can start rotating.

Also the disconnecting of the PTO-drive shaft from the MR-device requests a manual interventions: after the work has been terminated, with the PTO off; the device must be opened disengaging the drive shaft from the PTO. It is now possible to remove the drive shaft end from the U-bracket, according the following steps:

- the group represented by the U-bracket and the locknut must be rotated until the groves are in vertical position (fig.7-a);
- by pressing the lever of the wing-nut lock, the locknut is released and can be extracted from the U-bracket: the disconnection has been completed (figs. 7-b and 7-c;)
- the MR-device should be closed again, after the disconnection, the in order to increase its compactness and protect the mechanism.

Figure 7. Operation sequence of the manual phase of the connection of the PTO-drive shaft to the MR-device

Tests on the MR-device

The tests regarded the reliability of the device, observing its behaviour during the execution of a high number of automatic engagement-disengagement cycles. Further observations regarded the easiness of use and the reduction of the fatigue and discomfort for the operator in comparison with manual connecting and disconnecting. Because of their nature, these last points could not be measured with instruments. The evaluation resulted from an accurate observation of the different phases of the operation compared with the manual operation commonly experienced. A relevant part of these observations regarded the use of the device during normal field work, also collecting the impressions of the farmers.

Reliability of the MR-device

The tests regarded the mechanism of engagement/disengagement, involving both the mechanic and electro-hydraulic components. They have been conducted using a test bench suitably developed, capable to continuously operate cycles of engagement/disengagement. The test bench (fig. 8) reproduces a tractor's PTO equipped with the MR-device and a modified PTO-drive shaft that must be engaged/disengaged on it.

The manual connecting and disconnecting between the PTO-drive shaft and the U-bracket of the MR-device on the test bench are identical to those described in the previous paragraph and the time intervals they require have been measured in these tests.

Figure 8. Test bench with the PTO-drive shaft connected and control board

The opposite part of the PTO-drive shaft had a traditional system for the connection with the PTO tang and has been use for observing the manual connecting/disconnecting. Instead of the low-pressure hydraulic system of the tractor, the MR-device was fed by a independent hydraulic pump electrically driven. The control board has been equipped with a timer allowing the automatic, continuous repetition of the desired number of cycles, at a pre-set time interval between two cycles. A spring-lever based mechanism determines, after every cycle, a random rotation of the PTO tang, with the aim of changing its position (referring to the drive shaft PIC), testing the efficiency of the V-splayed teeth in facilitating the engagement and observing their wear and lifetime as a consequence of eventual cases of jam. Finally, the test bench was equipped with a pressure relief valve aimed at releasing the hydraulic pressure when the jam occurred. As to the automatic engagement/disengagement, it is almost instantly operated when the control button is pressed. As a consequence, most of the attention has been pointed on the behaviour of the MR-device in performing a series of cycles repeated at interval of 3 s, observing the

Figure 9. Tractor and operating machine during the field test of the MR-device

frequency of the jam events and consequently verifying the wear of the teeth.

Field tests on a tractor

The MR-device has been mounted on a New Holland M160 tractor coupled with a combined machine, for the sowing of wheat, with a rotary harrow. This consisted of 10 horizontal axis rotors with 25cm long tines. The working width was 3 m. The tests have been conducted on a previously ploughed, dry clay soil, with high slope values (fig.9).

The figure 10 shows some instants of the insertion of the PTO-drive shaft locknut into the bracket of the MR-device before starting the work.

Figure 10. Manual phase of the connection of the PTO-drive shaft to the MR-device mounted on a tractor before starting field work.

Test results

Test bench

The mean time required by the execution of the sequence of manual operations for the connection of the PTO drive shaft to the MR-device (fig. 6) has been 13 s, as for the manual disconnection (fig. 7) it has been 10 s.

As regards the automatic engagement/disengagement between the PTO-drive shaft PIC and the PTO tang, the complete cycle has been repeated 406 times, by means of the described test bench, corresponding, at least, to 1 years of traditional use. The observed cases of jam have been 28 (corresponding to 6.9% of the total) and have been overcome for effect of the described pressure relief valve. The V-shaped edges of the teeth did not show signs of damaging or wear.

Field

After an initial brief training, the operator became capable to easily execute the manual phase of the connection, requiring time intervals similar to those measured at the test bench. As previously said, the working conditions have been quite severe, with average PTO power requirements of about 90 kW. The frequent, abrupt changes of slope conditions, the high soil tenacity (depending on the high clay contents associated to the low humidity) and the surface unevenness determined frequent shocks on the PTO zone that, at any rate, did not affect the steadiness of the engagement between PTO tang and drive shaft PIC. The functionality of the

engagement/disengagement, tested several times during the work and at the end, kept in perfect efficiency, showing its reliability.

When the MR-device is installed on a tractor, it can not be provided with the "anti-jam" pressure relief valve because the thrust of the hydraulic cylinder could be insufficient to normal working for the presence of dust etc. If the jam occurs, it can be easily overcome by means of an instant PTO engagement that operates a slight rotation sufficient to unlock the apices of the jamming teeth.

Particularly positive have been the impressions of the operators that declared to find the device very useful in the reduction of the fatigue and discomfort determined by the manual connection of the PTO-drive shaft and considered it a valid support even from the point of view of safety.

Conclusions

The device reached the objective of the reduction of manual intervention in the connection on the PTO-drive shaft to the tractor PTO. After having equipped the tractor with it, manual intervention consists of the insertion of the drive-shaft locknut in a proper bracket on the device, as actual engagement/disengagement operations between the PTO tang and drive shaft PIC are controlled from the control board and electro-hydraulically operated every time it is needed. As a consequence, the time requested by the operations are significantly reduced and the conditions of fatigue and discomfort are substantially eliminated. Notwithstanding, as the traditional connecting and disconnecting operations depend on factors as the ability of the operators, the maintenance conditions of the machinery and their characteristics, it is difficult to provide an objective evaluation of said advantages.

The MR-device allows to automatically interrupt, from the cab, the transmission of PTO rotation and power, without detaching the PTO-drive shaft. This function can be used in different situations as during road transfers of the tractor-operating machine system, preventing mechanic damages.

Because of its easiness, the disengagement of the PTO-drive shaft PIC from the PTO tang could become a common practice, mostly in the cases in which it, normally, is not operated, preventing the risk of accidental PTO engagement, occurring, for instance, during the inspection of some parts of an operating machine after an inconvenient in field (as the flooding of a roller-baler).

In 2003, after a series of tests conducted by CRA-ING (Monterotondo, Rome), the MR-device obtained the ENAMA certification according to the "Protocol for the evaluation of the performances of the devices for coupling, towing and lifting systems - Cat. 40b" (ENAMA, 2003).