Developing and testing of a device to disengage the power transmission between tractor and feed mixer wagons

Bisaglia C.[1], Delmastro R.[2]
[1]*CRA-Unità di ricerca per l'ingegneria agraria (CRA-ING), Laboratorio di ricerca di Treviglio. Via Milano 43, 24047 Treviglio (BG), ITALY. Tel/Fax 0039 036349603, carlo.bisaglia@entecra.it*
[2]*CNR-Istituto per le macchine agricole e movimento terra (CNR-IMAMOTER), Strada delle Cacce 73, 10135 Torino, ITALY. Tel 0039 01139771, Fax 0039 0113489218, r.delmastro@imamoter.cnr.it*

Abstract
The risk of contact between the operator and the augers of a self-loading horizontal-type feed mixer wagon is one of the most critical situations connected to the safe use of these machines. To prevent this hazard, a research project funded by the Italian body for the agro-mechanical industry (ENAMA) and carried out by Comer Industries, Reggiolo, Italy, with the scientific support of CRA-ING and CNR-IMAMOTER research institutes, has been planned. A transmission device consisting of an automatic limiter able to disengage or to reverse the augers movement has been designed and tested. Aims of the device were: *i)* to transmit the torque required to the augers without limitations during the normal working process; *ii)* to continuously detect the torque values reversing the augers rotation if threshold values are exceeded and *iii)* to continuously detect the position of the rear self loading device stopping the augers when the loading arms are raised. Tests were carried out both in laboratory and in farm conditions; in this last case, the device was fitted into the driveline of a self-loading 10 m^3 feed-mixer wagon driven by a tractor PTO. The test ration was composed of an high quota of long stemmed hay quickly loaded into the mixing box in order to reproduce an high torque demand on the augers thus soliciting the intervention of the limiter. Laboratory tests show that the disengagement of the power from the tractor and the intervention of the internal brake, takes a short time to be realised and it occurs when the pressure of the oil exceeds a set value. Moreover, the functional parameters show that the reversion of the rotation in case of mixing box overloading, concurs to avoid the need for the operator to keep in contact with the augers to clear them.

Keywords: safety, sensor, automatic PTO disengagement.

Introduction
Self-loading horizontal-type feed mixer wagons (FMWs) represent a particularly dangerous category of agricultural machines for at least two main raisons; firstly, as many other agricultural tools, they are powered by a tractor power take-off (PTO) thus exposing the operator to the risk of become entangled in the implement input driveline (IID). Many case reports, unfortunately, testify this type of accident in feed mixer wagons operations (NIOSH-FACE Program, 2002a; 2003) as consequence of the specific tasks to be accomplished in the front side of the wagon during feeding (i.e.: adjust and check the electronic scale display, invert the sense of rotation of the IID, operate some controls, etc.). Secondly, the self-loading horizontal-type feed mixer wagons to be operated need that the worker approaches also the rear side of the machine and its uncovered moving parts – in particular augers and loading device – to push the uncollected feed closer to the loading device, to adjoin additives to be inserted in small quantities, to clear the augers from possible wrapping of long stemmed

forages, to inspect the regularity of the chopping-mixing process, etc. Also in this case, the literature reports accidents occurred, with always devastating consequences for the operator (NIOSH-FACE Program, 2002b).

A specific standard rule for this kind of machines (EN 703: 2004) has been developed in order provide design guidelines for manufacturers.

Besides, local programs to inform and to advise the farmers on the correct use of feed mixer wagons (i.e. Wisconsin FACE, 2007) have been carried out.

Moreover, several researches have been done to develop novel safety systems for tractor powered machines taking into account both the possibility of modifying the tractor transmission (Thomas and Buckmaster, 2005) or to apply safety sensors (Venem *et al.*, 2006), whether still at prototype level.

Aim of this research project was to design a system focused on horizontal type feed mixer wagons including both transmission and sensors safety components. The project was funded by the Italian body for the agro-mechanical industry (ENAMA) and carried out by the manufacturer Comer Industries, based in Reggiolo, Italy, and planned with the scientific support of CRA-ING and CNR-IMAMOTER research institutes.

A transmission device consisting of an automatic limiter able to disengage and/or to reverse the movement of the mixing augers under the control of sensors has been designed and tested.

Materials and methods

Aims of the purpose-designed device were: *i)* to transmit the torque required to the augers without limitations during the normal operation of the mixer; *ii)* to continuously detect the torque values at the wagon level and reverse the augers rotation if a set threshold value is exceeded; *iii)* to continuously detect the position of the rear self loading device and to disengage/stop the augers rotation when the loading arms are in their raised position. The device was designed to be integrated in the gearbox reducer of a trailed horizontal-auger feed-mixer wagon and consists of oil-bath clutch disks, hydraulically driven. The clutch engages or disengages the mixing augers if anomalous values, imposed by the manufacturer, occur and/or depending on the cutter arms' position. This working mode enables the operator to leave the manual controls area and get close to the rear of the wagon to load manually some diet components. Moreover, the system is able to invert automatically the sense of rotation of the augers in case of their blockage due to the wrapping of long stemmed forages.

Secondary aim of the project was to produce an universal device that could be fit also on second-hand mixers in order to improve the safety conditions of these machines. Tests were carried out both in laboratory and in farm conditions.

Laboratory tests

The tests in laboratory conditions (Figure 1) were necessary to set up the sensors and the electronic control unit (ECU) both in the case of disengagement of the power and in the case of reversion of the rotation.

The test bench was composed by an electric engine connected to a gearbox that transmitted the drive to the main shaft of the limiter device and by a dynamometer that provide the load simulating the mixing action. Thanks to this configuration it was possible to reproduce different situations – also the most critical ones – that may be checked during the work cycle of a trailed feed mixer wagon.

The sensors fitted on the limiter and controlled by the ECU were two oil-pressure gauges, a torque meter and two shaft revolution counters. Three main button controls were

prepared to operate the ECU of the device ("start mixing", "stop mixing", "auger inversion") and all the functions scheduled have been tested. The laboratory assessments were replicated for 100 test cycles.

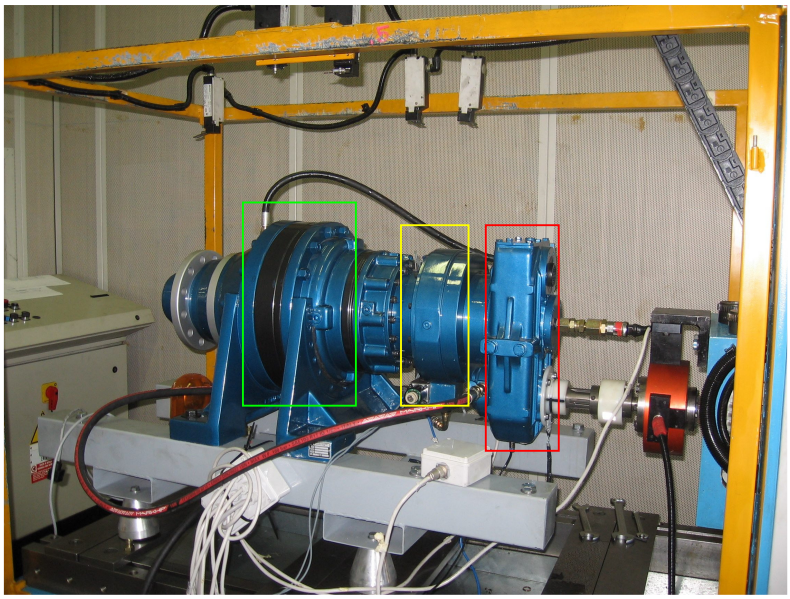

Figure 1. The test bench arranged for the automatic limiter' sensors and electronic unit set up (the automatic limiter = yellow square; the gearbox reducer = red square; the dynamometer = green square).

The main functions planned for the ECU were as follows:

1. running inhibition whether only one of the sensor detects anomalous values at the starting of the MFW;
2. starting of the augers rotation when pushing the "start mixing" button;
3. stop of the augers rotation when pushing the "stop mixing" button;
4. starting of the reverse rotation of the augers when pushing the "auger inversion" button; this counter rotation action is automatically maintained for a maximum of 15 seconds. In this case a 2.5 reduction factor of the auger speed in counter-rotation is adopted;
5. stop of the rotation to the MFW whether the pressure values are greater of a set threshold;
6. stop of the rotation to the MFW whether the pressure values are lower of a set threshold;
7. stop of the rotation to the MFW if a difference between the speed from the tractor PTO and the expected speed to the MFW shaft is recorded;
8. stop of the rotation to the MFW whether torque values are greater of a set threshold;
9. in the case of raising of the loading arms:
    a. stop of the rotation to the MFW,
    b. inhibition of the start of the transmission to the augers,
    c. stand of the augers rotation till the loading arm come back in their lower position,
    d. automatic re-start of the augers when the loading arms are completely lowered;
10. in the case the PTO stops:
    a. stop of the rotation to the MFW,
    b. inhibition of the start of the transmission to the augers,
    c. stand of the augers rotation till the PTO speed exceeds a minimum set value,

d. automatic re-start of the augers when the PTO re-starts.

For all the previous conditions has been assessed that the "stop mixing" button stops the rotation to the FMW and inhibits the automatic re-start of the safety systems.

Farm conditions tests

The tests in farm conditions were intended to assess the functionality of the device during the preparation of a standard TMR (total mixed ration) for dairy cows. In this last case, the device was fitted into the implement input driveline (IID) of a self-loading feed-mixer wagon, driven by the PTO of a standard agricultural tractor (Figure 2).

For this purpose, a new function has been added in the control system in order to consider the case of the tractor that moves and draws the wagon; if the PTO is disconnected during the displacement, the safety device automatically stops the augers rotations and inhibits its movements till the tractor PTO is re-started.

Also in the farm conditions the machine running is inhibited whether only one of the sensor detects anomalous values at the starting of the MFW, but in this case a sound signal and a flashing light inform the driver of the trouble.

Figure 2. The 10 m^3 trailed horizontal-auger self-loading feed mixer wagon used for the farm tests; 1) limiter device; 2) sensors for the loading arms position; 3) the ECU positioned in a safe working place inside the tractor cab.

A particular of the transmission limiter is showed in Figure 3 where the detailed position of some sensors are also showed (two oil pressure gauge into the limiter gearbox and two speed sensors, these last respectively at the inlet and at the outlet of the limiter). A torque-meter was interposed in the tractor-wagon driveline.

An on-board datalogger permitted to recording of the data. Five replications of the TMR preparation have been carried out in a commercial dairy farm using a 10 m^3 nominal volume feed-mixer wagon, with horizontal augers and a rotating silo-unloading device.

The feeding ration was composed of an high quota of long stemmed hay (for a total ratio of 31.5%, w.b.) quickly loaded in round bales into the mixing box (150 to 290 kg/min working rate); besides, the mixing volume of the hopper was completely filled (1230 kg of

TMR) in order to reproduce an high torque demand on the augers level to chop the steams and to mix the components thus soliciting the intervention of the limiter or provoking an overload.

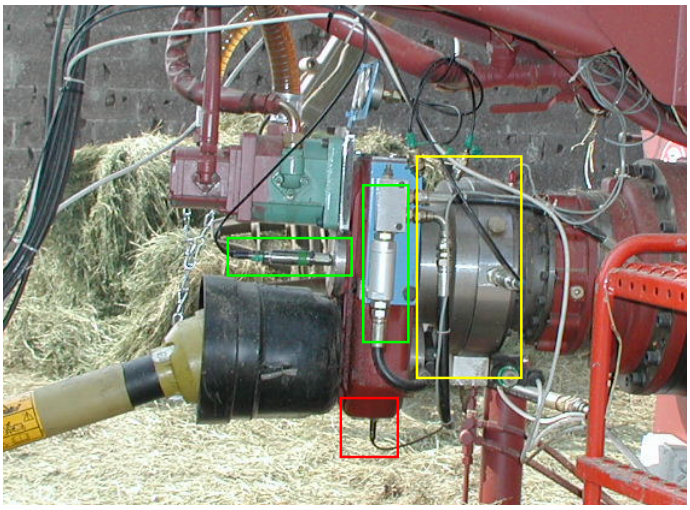

Figure 3. The automatic limiter (yellow square) fitted in the IID of the trailed, self-loading feed-mixer wagon. Sensors assist the limiter to monitor the set work conditions of the FMW (two oil pressure gauges = green squares; one input speed sensor = red square).

Results

Laboratory test

Laboratory tests show that the disengagement of the power from the engine and the intervention of the internal brake, takes a short time (0.04 s av. time) to be realised and it occurs when the pressure of the oil exceeds a set value. Moreover, the functional parameters reproduced at the bench (table 1), show that the reversion of the rotation in case of overloading of the mixing box, occurs without problems thus avoiding the need for the operator to keep in contact with the augers to clear them of the overload.

Table 1. Torque transmission capacity of the limiter in normal and reverse rotation

Parameter	Shaft rotation	
	normal	reverse
Engine speed (min^{-1})	540	540
Engine torque (kN)	911.3	346.3
Output torque (kN)	29430	29430
Hydraulic pressure (kPa)	2000	2000

Farm conditions tests

Figure 4 shows the results recorded during a typical TMR preparation where any problem has been registered or provoked in order to solicit the transmission limiter. The working period was divided into five phases correspondent to: the load and the chop of hay in

round bales (phase 1); the self-load of silo maize (phase 2); the chopping-mixing action (phase 3) and the unload of the final TMR into two different mangers (phases 4 and 5).

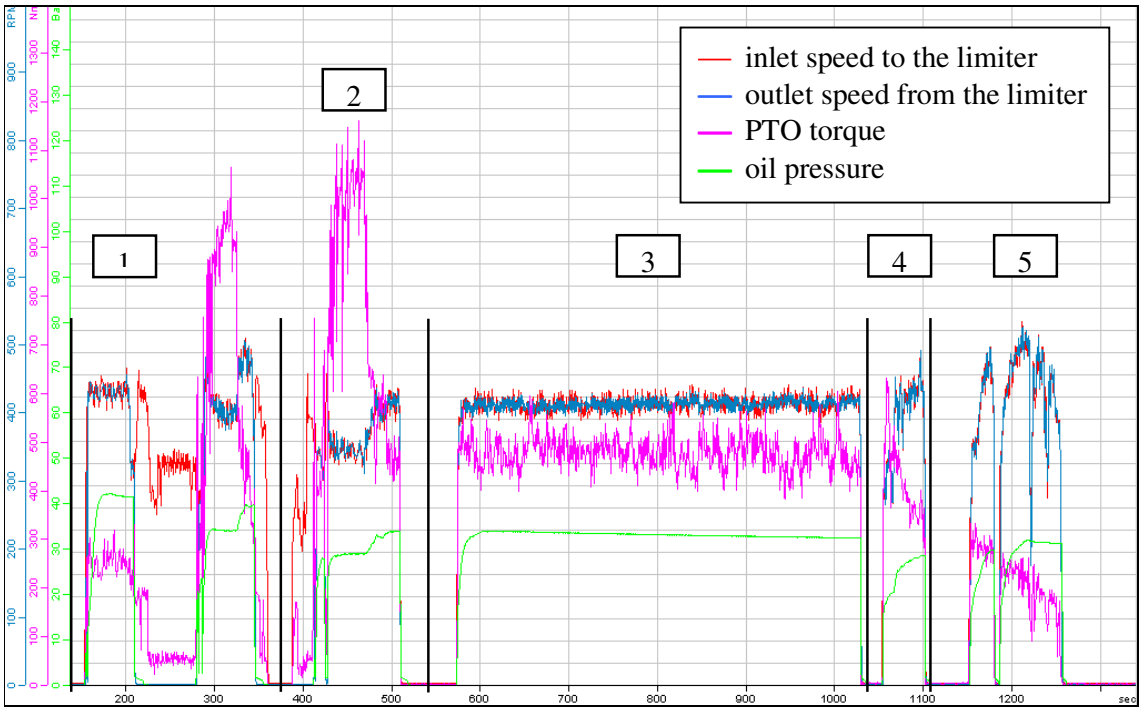

Figure 4. Typical trend of monitored parameters during TMR preparation for dairy cows in different working phases (1=load/chop of hay; 2= load of silo maize; 3=chop and mix of the ration; 4 and 5=unload on the TMR).

As shown, the speeds from the PTO and to the MFW (inlet and outlet speeds to and from the limiter) are quite almost coinciding because the slipping of the clutch occurs only in two occasions: at the start of the wagon (probably due to the too high PTO speed selected for the showed test) and after the hay round bale load and chop where the torque measured at the PTO suddenly reach a peak of 1050 Nm. During the silo maize loading phase the torque values were higher (1200 Nm) both because of the quantity loaded (1071 kg of silo maize) and the intervention of the hydraulic silo cutter drum (668.1 kg min^{-1} av. working rate); nevertheless these values were obtained more gradually in comparison with the previous phase as the lower rotating speeds (500-560 min^{-1}) and the maximum oil pressure values (3000-3500 Kpa) confirm. After the phase 2, the PTO was disengaged to manually load the concentrates.

Tests were replicated in order to provoke an overload of the wagon mixing system; the most probable phase for this kind of event is the hay load phase. Figure 5 shows one of the case occurred and reports the actions carried out by the operator to re-start the working process. As shown in the figure, the suddenly increase of the torque value (> 1800 Nm) due to the wrapping of hay on the augers, produced the contemporary reduction of both the inlet and the outlet speeds at the limiter level without recording any clutch slip; this behaviour is confirmed by the coincident trend of the two relevant curves; the oil pressure also drops and the tractor engine stops. After this trouble, the operator tried to re-start the tractor two times

without success because the safety system sensors detected too high levels of torque due to the augers blockage.

The operator decided to push the "auger inversion" button, thus causing the counter rotation of the augers and their clearing from the long stems of hay wrapped around. The figure shows that the outlet speed in counter rotation (blue line) was 2.5 lower than the inlet one as set (av. 240 min^{-1} *vs.* 600 min^{-1}). The single counter rotating action performed had 12 s lasting and was sufficient to clear the augers; after that the working process was re-started and accomplished without any risk exposure for the operator.

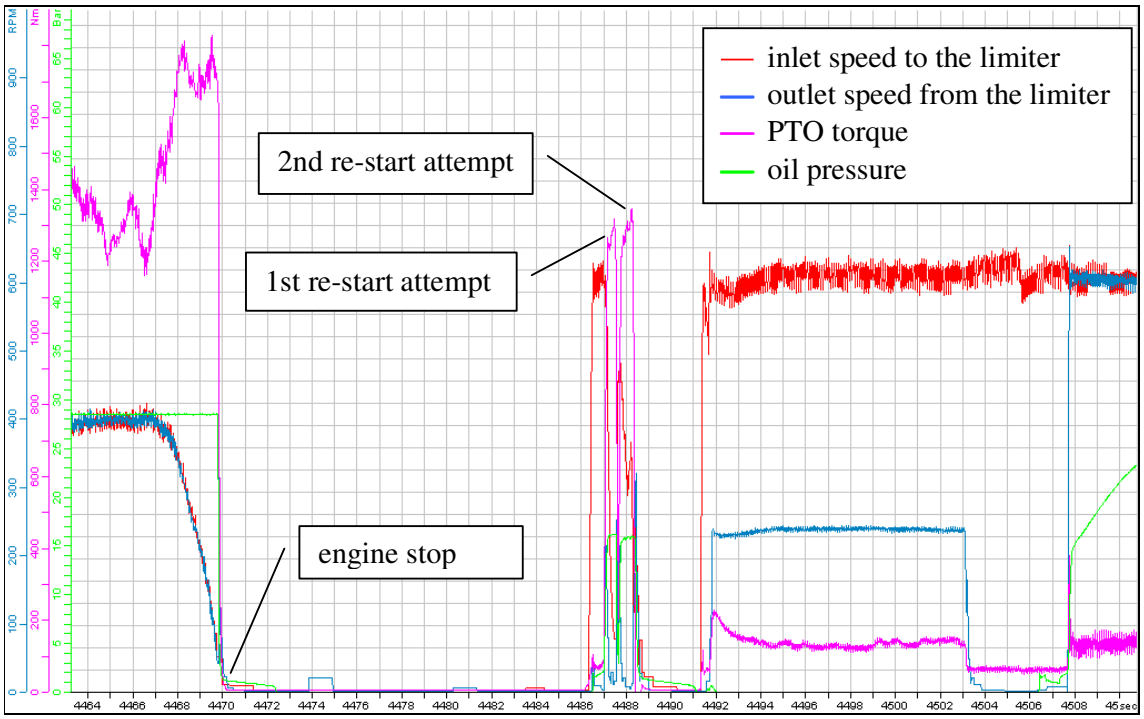

Figure 5. Trend of monitored parameter during an augers blockage due to the wrapping of long stemmed hay.

Conclusions

The use of an automatic disengagement device on a trailed feed mixer wagon has demonstrated to be an effective tool in order to manage the main dangerous operations deriving from the TMR preparation process; the possibility of trouble solving directly from the tractor seat reduces the risk for the operator to became in contact with mechanical rotating parts. In particular, the following conclusions can be drawn from this tests:

- the automatic limiter device assisted by sensors can transmits the torque required to the augers without limitations during the normal working phases of the mixer, but automatically stopping their motion if set threshold values are exceeded;
- the possibility of reversion of the augers rotation can solve auger blockage with few interventions without exposing the operator to the risk of contact with the augers or with the PTO shaft;

- to strengthen the safety conditions supported by the limiter device, an automatic auger stopping system has been set up, depending to the rear loading arms position.

Acknowledgements
The research was carried out with the financial support provided by the Italian National Body for the Agro-mechanical Industry (ENAMA).

References

European Standard EN 703:2004. Agricultural machinery. Silage loading, mixing and/or chopping and distributing machines. Safety. European Committee for Standardization, Brussels.

NIOSH (National Institute for Occupational Safety and Health)-FACE (Fatality Assessment and Control Evaluation) Program 2002a. Farm laborer killed when he became entangled in an unguarded PTO shaft. Michigan case report n. 2002MI151.

NIOSH (National Institute for Occupational Safety and Health)-FACE (Fatality Assessment and Control Evaluation) Program 2002b. Youth farm worker dies after falling into operating feed grinder/mixer – Ohio. NIOSH in house report n. 2002-10.

Wisconsin Fatality Assessment and Control Evaluation (FACE) program 2007. Avoid serious injury or death from Total Mixed Ration (TMR) mixers. Wisconsin Department of Health and Family Services.

NIOSH (National Institute for Occupational Safety and Health)-FACE (Fatality Assessment and Control Evaluation) Program. 2003. Farm worker dies after becoming entangled in a power-take-off shaft. Minnesota case report n. 2003MN008.

Thomas R.S., Buckmaster D.R. 2005. Development of a computer-controlled, hydraulic, power take-off (PTO) system. Transaction of the ASABE, 48(5), 1669-1675.

Venem M.T., Shutske J.M., Gilbert W.J. 2006. Testing and creation of a safety system to disengage the PTO of a tractor. Applied Engineering in Agriculture, 22(1), 5-12.