Guard interlocking for PTO driven machinery

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Guard interlocking for PTO driven machinery

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The potential to reduce the likelihood of operator injury, by use of guard interlocking systems upon tractor PTO (power take-off) driven agricultural machinery, is investigated. Agricultural accident statistics, equipment sales data and design trends are reviewed to identify and assess the risk(s) associated with PTO driven machines; to identify pertinent tractor and implement design features; and to identify potential guard interlocking systems that may be utilised on PTO driven machinery. Alternative interlock system implementations are proposed, with consideration of the design features and operating characteristics / environments of high-risk agricultural implements and attached tractors. The installation of a demonstration guard interlocking system upon a representative high-risk PTO driven implement (big square baler) is described and the results of a subsequent laboratory and field evaluation programme, undertaken to monitor the functionality and robustness of the system during typical field operation, are presented.

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CONTENTS

ACKNOWLEDGEMENTS iii

CONTENTS v

EXECUTIVE SUMMARY vii

1 INTRODUCTION 1

1.1 Background 1

1.2 Objectives 4

2 IDENTIFICATION AND RISK ASSESSMENT OF PTO DRIVEN IMPLEMENTS 5

3 REVIEW OF TRACTOR DESIGN FEATURES 7

4 GUARD INTERLOCKING SYSTEMS 11

5 failure mode and effects analysis 15

6 GUARD INTERLOCKING SYSTEM DESIGN 18

6.1 Selection of target implement 18

6.2 Interlocking system design 19

7 INTERLOCK SYSTEM TESTING 26

8 DISCUSSION 28

9 CONCLUSIONS 30

10 REFERENCES 31

APPENDIX 1 NH D1010 BALER SPECIFICATIONS 32

APPENDIX 2 INTERLOCKING SYSTEM COMPONENTS 34

APPENDIX 3 INTERLOCKING SYSTEM WIRING DIAGRAM 35
EXECUTIVE SUMMARY

This report describes research undertaken concerning the development of a prototype guard interlocking system (interlocking PTO (power take-off) driveline de-coupling with the existing implement hinged guards), suitable for use with a wide range of PTO driven agricultural machinery in the UK.

Detailed reviews were undertaken to identify and assess the risk(s) associated with PTO driven machines; establish current, near-future and recent past tractor design features (especially related to PTO driveline control); and determine potential guard interlocking systems that may be utilised on PTO driven machinery.

Potato harvesters, trailed forage harvesters and pick-up balers are identified as implements that are the most frequently implicated in machinery-contact related accidents. It is also established that, because of the range of PTO engagement systems utilised on the UK tractor fleet, an independent PTO power interruption device (PTO driveline clutch), would be obligatory for any interlock system to be universally applicable. A control interlocking system is therefore required that has authority over the PTO driveline clutch and, where fitted, the guard-locking interlock switches.

Schematics of possible guard interlocking system designs are given and the results of a failure mode / effects analysis undertaken on the system components is taken into account in the final interlocking system design.

A big square baler was selected as the most suitable implement on which to construct the demonstration interlock system and details of the baler are provided. The safety strategy adopted for this implement is summarised and the design and construction of a guard interlocking system to fulfil this strategy is described.

The interlock system components were selected from commonly available industrial specification safety components, but a 24 volt DC power supply was required in addition to the 12 volt DC supply available from the tractor. Although no suitable independent clutch was located for this high torque application the same safety interlock system design was used and PTO power interruption accomplished by hard-wiring the baler interlock system to an existing interlock signal to the tractor’s electro-hydraulic PTO clutch control module.

A full laboratory and field evaluation programme was successfully completed and although minor operational difficulties were encountered the PTO interlock system demonstrated no loss of safety function during typical straw baling field conditions.
1  INTRODUCTION

1.1  BACKGROUND

A wide range of PTO (power take-off) driven machinery is commonly used in conjunction with agricultural tractors in the UK. These implements can be both front and/or rear mounted on the tractors’ 3 point linkage or trailed via the tractor drawbar, as illustrated in the following photographs. However, despite the increasing levels of comfort and hazard protection afforded to the operators of modern agricultural tractors, due to continuing developments in cab and general vehicle design, the PTO driven machines attached to them remain a major source of potential danger.

*Photograph courtesy of Kverneland*

*Front and rear mounted PTO driven implements - power harrow air drill combination with front-mounted seed hopper (Kverneland)*

*PTO driven, impeller-type, side discharge FYM (farmyard manure) spreader (Dowdeswell Multispread)*

*Photograph courtesy of Kverneland*
Chestney studied the frequency and specific nature of power driven machinery-related accidents and concluded that improvements to the guarding were required and some form of guard interlocking would be beneficial. Dwyer and Sanders concluded that the options available for improving the safety of tractor-implement mechanical power transmission were:

1. Improving the nature and durability of PTO driveline shielding
2. Transmitting power to the implement by some non-mechanical means
3. Employing a device to automatically de-couple the PTO driveline when a person enters the hazard envelope.

The possibilities of implementing solutions (i) and (ii) have been the subject of previous investigations and concentrated on reducing or eliminating the potential danger posed by the PTO shaft connecting the tractor and implement, an example of which is shown in Figure 1. However, as Dwyer and Sanders highlighted, this does not reduce the potential hazard caused by other powered mechanisms downstream of the PTO shaft, such as those normally enclosed by hinged guards (Figure 2). In this case solution (iii) would offer a significant advantage by protecting the operator from any moving components within the defined hazard envelope, assuming that such a system could be readily and economically incorporated into agricultural field machinery.

![Figure 1](image.png)

**Figure 1** Typical PTO telescopic shaft guard

Hinged guards are normally provided where frequent access is required for maintenance or adjustment of the enclosed mechanism(s). In many current machine designs the guards may be opened with the PTO drive engaged, thereby exposing the operator to potentially fatal risk. The use of an interlocking system on hinged guarding, which would automatically disengage the drive to the machine when the guard was open(ed), would retain ease of maintenance access but prevent inadvertent operator exposure to powered drives and mechanisms. However, for this type of interlock system to be acceptable to both the regulatory authorities and the machine operator the system must fulfil its primary safety function, but not unduly restrict normal safe machine operation and routine maintenance. Where the implement workrate is compromised due to “nuisance tripping” of an additional safety system, or downtime significantly increased because of more restricted access, the operator may be tempted to override or by-pass the interlock system (O’Neill). Any interlock system must therefore be totally reliable both in
terms of interrupting the PTO drive to the machine when a guard is open(ed), but also by ensuring uninterrupted machine operation, during exposure to typical field operation conditions, when all guards are in place and/or closed. Typical operating conditions of agricultural implements could expose any interlock system to vibration, dust, moisture, shock loading and temperature variation therefore a robust system is required.

![Figure 2](image)

**Figure 2** Typical hinged panel guards allowing access to internal mechanism

CEMAGREF explored the guard interlocking concept on PTO driven machinery by implementing a prototype system on a tractor / round baler combination (New Holland 8340 / Claas Rollant 46). Interlocked access panels and safety stops on the baler were connected, via a bespoke control module, to the electro-hydraulic tractor PTO engagement system. When the guard interlock system was activated, the tractor PTO clutch solenoid was de-energised, disengaging the PTO drive to the baler. Although this implementation offers a relatively inexpensive system of interlocking (2 –5% of the baler purchase price) it is not applicable to tractor / implement combinations where the tractor PTO is not electro-hydraulically engaged.

Other researchers, including Shutske *et al.* have evaluated human presence sensors and their use in agricultural machine operation environments. They have primarily concentrated upon determining the ability of commercially-available sensors to detect a worker approaching the hazard zone between a tractor and trailed, PTO-driven implement, and have demonstrated very promising results. Use of human presence detection systems, in relation to guard interlocking systems, is fully examined in a related investigation by Scarlett *et al.*
1.2 OBJECTIVES

The overall objectives of this investigation were therefore as follows:

- To identify and assess the risk associated with PTO driven implements in current use in the UK;

- To review modern tractor design features that directly affect the design requirements of a guard interlock system; and

- To design, construct and evaluate a prototype guard interlocking system which would be suitable for a wide range of PTO driven agricultural machinery, on a representative implement.
2 IDENTIFICATION AND RISK ASSESSMENT OF PTO DRIVEN IMPLEMENTS

UK sales volumes of most PTO driven machines have reduced during the 1990’s (see Table 1) due in part to restructuring within the farming industry, which has resulted in fewer but larger machines being purchased. An estimate of the number of PTO driven machines in current use is given (Table 1), calculated from sales data and estimates of the useful machine life (Nix7).

Table 1 Recent UK sales of PTO driven machinery and estimated machine pool

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Power harrow</td>
<td>2600</td>
<td>2350</td>
<td>2500</td>
<td>2625</td>
<td>2017</td>
<td>1435</td>
<td>2099</td>
<td>11403</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertiliser distributor</td>
<td>4615</td>
<td>3231</td>
<td>3000</td>
<td>3092</td>
<td>3969</td>
<td>4800</td>
<td>4431</td>
<td>3568</td>
<td>2309</td>
<td>2453</td>
<td>16722</td>
</tr>
<tr>
<td>FYM spreader</td>
<td>2011</td>
<td>1649</td>
<td>1850</td>
<td>2493</td>
<td>2433</td>
<td>2031</td>
<td>1200</td>
<td>700</td>
<td>750</td>
<td>7094</td>
<td></td>
</tr>
<tr>
<td>Slurry spreader</td>
<td>2553</td>
<td>2170</td>
<td>2400</td>
<td>2885</td>
<td>2757</td>
<td>2655</td>
<td>1711</td>
<td>1400</td>
<td>850</td>
<td>900</td>
<td>8322</td>
</tr>
<tr>
<td>Rotary mower</td>
<td>2353</td>
<td>1882</td>
<td>2000</td>
<td>2000</td>
<td>2024</td>
<td>2141</td>
<td>2235</td>
<td>2200</td>
<td>2100</td>
<td>1950</td>
<td>12329</td>
</tr>
<tr>
<td>Mower conditioner</td>
<td>2043</td>
<td>1532</td>
<td>1675</td>
<td>2165</td>
<td>2022</td>
<td>1920</td>
<td>1961</td>
<td>2100</td>
<td>1950</td>
<td>1850</td>
<td>11475</td>
</tr>
<tr>
<td>Conventional baler</td>
<td>388</td>
<td>372</td>
<td>310</td>
<td>217</td>
<td>194</td>
<td>267</td>
<td>322</td>
<td>320</td>
<td>225</td>
<td>170</td>
<td>1634</td>
</tr>
<tr>
<td>Round baler</td>
<td>1629</td>
<td>1434</td>
<td>1450</td>
<td>1629</td>
<td>1450</td>
<td>1922</td>
<td>1385</td>
<td>1560</td>
<td>1025</td>
<td>1050</td>
<td>8762</td>
</tr>
<tr>
<td>Big square baler</td>
<td>236</td>
<td>191</td>
<td>130</td>
<td>104</td>
<td>201</td>
<td>312</td>
<td>430</td>
<td>250</td>
<td>150</td>
<td>180</td>
<td>1403</td>
</tr>
<tr>
<td>Potato harvester</td>
<td>301</td>
<td>262</td>
<td>310</td>
<td>301</td>
<td>442</td>
<td>536</td>
<td>394</td>
<td>165</td>
<td>229</td>
<td>286</td>
<td>1224</td>
</tr>
<tr>
<td>Forage harvester</td>
<td>1508</td>
<td>905</td>
<td>950</td>
<td>905</td>
<td>995</td>
<td>724</td>
<td>588</td>
<td>580</td>
<td>450</td>
<td>385</td>
<td>3977</td>
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<tr>
<td>Sprayer</td>
<td>1800</td>
<td>2000</td>
<td>2300</td>
<td>2200</td>
<td>2100</td>
<td>1950</td>
<td>1800</td>
<td>1100</td>
<td>1100</td>
<td>7618</td>
<td></td>
</tr>
</tbody>
</table>

The relative risk that each machine type poses to the operator depends on how the machine is normally used, the number of drives / mechanisms that can be potentially exposed, and operator proximity to the hazard envelope (e.g. manned platforms). From detailed investigations into power driven machinery-related accidents Chestney2 determined that potato harvesters, trailed forage harvesters and balers were by far the most frequently implicated PTO powered implements.

Although the number of fatalities due to contact with machinery varies between years, the 15 year average is currently 14% of all fatal injuries in farming forestry and horticulture (HSE - Field Operations Directorate8). Agricultural fatal accident and injury statistics also demonstrate that contact with machines is a relatively constant factor in non-fatal agricultural accidents, as illustrated in Figure 3. Not all of the accidents classified under ‘contact with machinery’ were due to direct contact with drive mechanisms and so would not have been prevented by a guard interlocking system. However, O’Neil3 found that guarding or safety devices were among the most common Significant Factors nominated in HSE Inspector’s reports of agricultural accidents.
Figure 3  Annual percentage of injuries due to contact with agricultural machinery
3 REVIEW OF TRACTOR DESIGN FEATURES

Recent UK agricultural tractor sales statistics, illustrated in Figures 4 and 5, indicate a general downward trend in the recent sales volume of tractors, but a steady increase in the average power of each unit.

Figure 4  UK sales volumes of tractors above 40 hp

Figure 5  Average engine power of tractors (above 40 hp) sold in the UK
By combining this information with the number of licensed tractors it is possible to estimate the likely number, age and power classification of tractors in current use in UK agriculture. This is illustrated in Figure 6 and indicates that there are approximately 100,000 licensed tractors less than eleven years old. However, other estimates of tractors in current use have ranged between 300,000 and 500,000, indicating that a significant number of older and/or unlicensed tractors are also still in regular use.

**Figure 6** Tractors currently licensed in the UK with respect to engine power

Although the exact specification of these tractors is not known, the vehicle age and engine power can be used, together with the tractor manufacturers original specifications and market share data, to give an indication of the PTO engagement system likely to be present. The main types of PTO engagement systems on agricultural tractors are:

- Mechanical
- Hydro-mechanical
- Electro-hydraulic

Both the hydro-mechanical and the electro-hydraulic PTO engagement systems usually incorporate automatic PTO driveline braking upon PTO clutch disengagement. However, it should be noted that these brakes have a relatively small capacity and are designed to hold the disengaged PTO shaft stationary and not to repeatedly brake full speed, high inertia, implement driveline loads to a standstill.

As detailed in Section 1.1, the CEMAGREF\(^4\) interlocking system utilised the existing electro-hydraulic PTO engagement system of the tractor to interrupt the PTO drive to the implement as required. However, as Figure 7 illustrates, although electro-hydraulic PTO engagement is
becoming standard across the industry, especially among higher specification, higher horsepower tractors, the other two PTO engagement systems are still produced and were the most common systems prior to 1994. This indicates that there are still large numbers of tractors in current use with which the CEMAGREF interlocking system would not be compatible.

![Pie charts showing the estimated proportion of agricultural tractors sold in the UK with each type of PTO engagement system.](image)

**Figure 7** Estimated proportion of agricultural tractors sold in the UK with each type of PTO engagement system

To be universally applicable to the current UK tractor fleet, any guard interlocking system would have to function equally well with all the PTO engagement systems. This implies that, as there is no common method of easily controlling the PTO clutch on tractors with different PTO engagement systems, an independent clutch in the PTO driveline would be required, controlled by the guard interlocking system, to achieve full compatibility with the current UK tractor fleet.

This will obviously be a more expensive solution than the system implemented by CEMAGREF (CEMAGREF estimated 5–10% of machine purchase price for a system incorporating an independent clutch), and it should be noted that other options for new tractors are becoming feasible. A number of tractor manufacturers already utilise Controller Area Network (CAN) technology for communication and control of tractor subsystems e.g. engine, transmission and implement hitch, and this type of system, illustrated in Figure 8, is likely to become more widespread in the future. Current product developments concerning CAN–based electronic systems for tractor–implement communication and control (e.g. ISO 11783) may eventually enable implement-originated messages to effect disengagement of the tractor PTO system.
A number of CAN communication systems operating in accordance with the ISO 11783 standard (coined ISOBUS) were demonstrated at the Agritechnica 2001 exhibition by a range of tractor and implement manufacturers. IMAG (Instituut voor Mechanisatie, Arbeid en Gebouwen) promoted the protocol by conducting compatibility testing of both hardware and software across the range of participating manufacturers. When this technology is fully adopted, tractor–implement guard interlocking systems may be implemented on ISO 11783 compliant equipment with much greater ease and at lower cost. This type of safety system will also have the advantage that it will be powered and operate through the same ISO tractor / implement connector as the implements control system, minimising the number of tractor / implement connections.

**Figure 8**  Schematic of possible CAN–bus network
4 GUARD INTERLOCKING SYSTEMS

The protective function of safety interlocking switches is achieved by interlocking the guard panels of a machine with the power source of the hazard. Figure 9 depicts a simple electrical safety control circuit where the guard interlock switch is directly connected in series with the power switching circuit, ensuring the power to the enclosed mechanism, via the contactor, is isolated when the guard is open.

Guard interlocks are in widespread use throughout manufacturing industry and, although safety interlocks are utilised in many agricultural vehicles (e.g. starting tractors in neutral gear), as yet there has been limited use of guard interlocking systems on mobile powered machinery. Although demonstration systems have been produced by CEMAGREF\(^4\) and Chestney\(^9\), they have not been taken up by agricultural machinery manufacturers. This may in part be due to a previous (perceived) reluctance of the farming industry to accept electrical / electronic control systems on equipment that is typically used in relatively arduous conditions. The increasing, and successful, use of robust electronics on both tractors and implements in recent years has demonstrated the reliability of electronic systems to the farming industry and should encourage the acceptance and use of industrial-type guard interlocking systems in agriculture.

Any guard interlocking system used on PTO driven equipment will be subjected to the typical agricultural environment i.e. dust, vibration, moisture and shock loads. There are three main types of switches used in safety circuits; force disconnected, orientated failure mode and duplication (or redundancy). Each of these switches has particular attributes but the common factor is that they are all designed to fail to a safe condition i.e. machine driveline de-coupled and/or power isolated. Most manufactures of guard interlock switches offer systems that are rated to IP65 - IP68 (protected against dust ingress and varying degrees of water resistance), some typical examples are shown in Figures 10 and 11.
In order to ensure effective and reliable interlock system selection and implementation, the machine application and hazard conditions produced by the implement have to be taken into account. All of the implements highlighted in Section 2 as high risk examples (potato & forage harvesters and balers) have hinged guards enclosing power driven mechanisms, and also incorporate mechanised components which interact with the crop and/or soil, which cannot be fully guarded by mechanical means. As the power transmission to these implements is mechanical, via the PTO shaft, a control interlocking system would be required. In this type of system the individual interlock switches and/or safety stops are connected to a control unit which also has authority over the power interruption device (tractor PTO clutch or alternative driveline disconnection device). Thus when any of the guard doors are open, either where the
operator requires to gain access for maintenance, or has not closed them following a period of access, the mechanical drive to the machine is isolated. For machine components that interact with the crop and/or soil Chestney\textsuperscript{1} suggested a photoelectric fence could be employed around the hazard area (as illustrated in Figure 12); whilst CEMAGREF\textsuperscript{4} utilised ‘grab wire’ type safety stop. As highlighted by Scarlett \textit{et al}\textsuperscript{6} there are a number of other methods which could be used to detect human presence in the vicinity of the hazard area such as physical contact, infrared emission, radar and capacitive sensors. However, there is a need to balance the hazard reduction which could be achieved using these devices with the likely incidence of false signals, (and resultant downtime), which would lead to operator frustration and possible rejection of the complete system.

A further hazard that is integral to a number of implements, including the baler and forage harvester, is the large flywheel that is utilised in the driveline to smooth fluctuating power requirements. These flywheels store significant amounts of energy and, combined with an overrun clutch in the driveline, result in the machine continuing to rotate, and so remain a potential hazard, for a considerable time after power to the PTO driveline has been disengaged. To overcome this situation guard locking interlock switches may be utilised which prevent guards being opened before the enclosed mechanism has come to a complete halt. This can be either after the natural run-down time of the implement, or following the application of a mechanical brake, located downstream of the overrun clutch, applied after the driveline has been disengaged. In both instances a motion sensor can be incorporated in the control circuit, to ensure that the implement mechanism has come to rest before the guard locks are energised to open (again the failure mode is to a safe condition i.e. guard locked shut). A potential interlock system layout for this type of implement is illustrated in Figure 13.

![Diagram](image-url)

\textbf{Figure 12} Schematic of guard interlock system suitable for crop and/or soil engaging implement
Figure 13  Schematic of interlock system suitable for PTO driven machine that contains a flywheel
5 FAILURE MODE AND EFFECTS ANALYSIS

A failure-mode and effects analysis (FMEA) was carried out on the outline interlocking system designs. A group of engineers (mechanical, electronic and service) was assembled to discuss the potential failure modes of each of the safety system components and predict the likely outcome of these failures. The results of this analysis are summarised in Table 2.

As can be seen from Table 2, the failure of some of the components (guard switch, guard lock and clutch engagement) could directly lead to the production of an unsafe condition of the implement, depending on which mode the component failure was orientated. Other failure paths (guard lock, brake switch, clutch engagement and motion sensor) would require multiple failures before the production of a dangerous situation, but again this would depend on which mode the failure was orientated.

As discussed in Section 4, industrial specification safety components are designed to minimise any loss of safety due to such failures. Depending on the hazard potential of the equipment being guarded, the safety components can incorporate force disconnected switches (to avoid contact welding); orientated failure mode switches (to ensure failure to the safest condition); and dual circuit redundancy (i.e. the need for two safe signals from each switch / lock before enabling PTO engagement). The output of these switches can be used to directly interlock with the power source of the hazard, or interlock via a control system that has authority over the power source and may also perform other functions. In either case there are two main principles which can be followed in the design of a safety system, i.e. towards the prevention of faults or towards the detection of faults (Guardmaster Safebook 29). As summarised in Table 3, Category 1 is aimed at the prevention of faults by the use of simple and reliable design & components within the safety system. Categories 2, 3 and 4 are based on the principle that where faults cannot be prevented they must be detected, by monitoring and checking the system, to avoid the production of an unsafe condition. It would therefore seem judicious to utilise existing industrial safety system components in the design of the PTO driven machinery interlock system, as these safety principles are fully incorporated in the component design and the components are well proven in industrial environments.
### Table 2  Summary of failure mode and effects analysis

<table>
<thead>
<tr>
<th>Interlocking system component</th>
<th>Failure mode</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guard switch</td>
<td>Guard apparently open</td>
<td>Unwanted shutdown with associated operator frustration</td>
</tr>
<tr>
<td></td>
<td>Guard apparently closed</td>
<td>Potentially dangerous situation if guard was open(ed)</td>
</tr>
<tr>
<td></td>
<td>Guard continuously locked</td>
<td>Operator frustration as access to machine denied after correct shutdown</td>
</tr>
<tr>
<td></td>
<td>Guard continuously unlocked</td>
<td>Potentially dangerous situation if guard was opened during operation, as perpetrator would be exposed to machine motion during rundown time (if the guard switch was operational), or to continuous motion (if the guard switch had also failed to give a “guard closed” signal)</td>
</tr>
<tr>
<td>Brake sensor switch</td>
<td>Brake apparently on</td>
<td>Unwanted shutdown with associated operator frustration. The operator could be exposed to unexpected motion of the mechanism if the flywheel had come to rest at an unstable condition e.g. baler plunger TDC</td>
</tr>
<tr>
<td></td>
<td>Brake apparently off</td>
<td>Operator frustration as access to machine denied after correct shutdown</td>
</tr>
<tr>
<td>Driveline clutch engagement</td>
<td>Clutch continuously engaged</td>
<td>Dangerous situation as access to moving drives would be possible if any guards are not locked or lock has failed to the unlocked state</td>
</tr>
<tr>
<td></td>
<td>Clutch continuously disengaged</td>
<td>Operator frustration as machine will not function</td>
</tr>
<tr>
<td>Mechanism motion sensor</td>
<td>Mechanism apparently stopped</td>
<td>Potentially dangerous situation as access would be enabled if brake was on or had failed on</td>
</tr>
<tr>
<td></td>
<td>Mechanism apparently rotating</td>
<td>Operator frustration as access to machine denied after correct shutdown</td>
</tr>
<tr>
<td>Power supply</td>
<td>No power</td>
<td>Operator frustration as unable to use machine or access guarded components</td>
</tr>
</tbody>
</table>
# Table 3: Description of safety interlock system requirements (Guardmaster Safebook 2\textsuperscript{th})

<table>
<thead>
<tr>
<th>Summary of requirements</th>
<th>System behaviour</th>
<th>Principle</th>
</tr>
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<tbody>
<tr>
<td><strong>Category B</strong> (see note 1)</td>
<td>When a fault occurs it can lead to a loss of the safety function.</td>
<td>By selection of components (Towards PREVENTION of faults)</td>
</tr>
<tr>
<td>- Safety related parts of machine control systems and/or their protective equipment, as well as their components, shall be designed, constructed, selected, assembled and combined in accordance with relevant standards so that they can withstand the expected influence.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Category 1</strong></td>
<td>As described for category B but with higher safety related reliability of the safety related function. (The higher the reliability, the less the likelihood of a fault)</td>
<td></td>
</tr>
<tr>
<td>- The requirements of category B apply together with the use of well tried safety components and safety principles.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Category 2</strong></td>
<td>The loss of safety function is detected by the check.</td>
<td>By structure (Towards DETECTION of faults)</td>
</tr>
<tr>
<td>- The requirements of category B and the use of well tried safety principles apply.</td>
<td>The occurrence of a fault can lead to the loss of safety function between the checking intervals.</td>
<td></td>
</tr>
<tr>
<td>- The safety function(s) shall be checked at machine start-up and periodically by the machine control system. If a fault is detected a safe state shall be initiated or if this is not possible a warning shall be given.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Category 3</strong> (see notes 2 &amp; 3)</td>
<td>When the single fault occurs the safety function is always performed.</td>
<td></td>
</tr>
<tr>
<td>- The requirements of category B and the use of well tried safety principles apply.</td>
<td>Some but not all faults will be detected.</td>
<td></td>
</tr>
<tr>
<td>- The system shall be designed so that a single fault in any of its parts does not lead to the loss of safety function.</td>
<td>An accumulation of undetected faults can lead to the loss of safety function.</td>
<td></td>
</tr>
<tr>
<td><strong>Category 4</strong> (see notes 2 &amp; 3)</td>
<td>When the faults occur the safety function is always performed.</td>
<td></td>
</tr>
<tr>
<td>- The requirements of category B and the use of well tried safety principles apply.</td>
<td>The faults will be detected in time to prevent the loss of safety functions.</td>
<td></td>
</tr>
<tr>
<td>- The system shall be designed so that a single fault in any of its parts does not lead to the loss of safety function.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- The single fault is detected at or before the next demand on the safety function. If this detection is not possible then an accumulation of faults shall not lead to a loss of safety function.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note 1:** Category B in itself has no special measures for safety but it forms the base for the other categories.

**Note 2:** Multiple faults caused by a common cause or as inevitable consequences of the first fault shall be counted as a single fault.

**Note 3:** The fault review may be limited to two faults in combination if it can be justified but complex circuits (e.g. microprocessor circuits) may require more faults in combination to be considered.
6 GUARD INTERLOCKING SYSTEM DESIGN

6.1 SELECTION OF TARGET IMPLEMENT

As detailed in Section 3, the three PTO driven implements which offer the highest potential risk of injury to operators are potato harvesters, forage harvesters and balers. In order to undertake extensive field testing within the investigation timeframe, it was decided to utilise a big square baler as the base machine for the demonstration guard interlocking system.

The specific model of baler utilised for the interlock system development was a New Holland D1010 “CropCutter”, as shown below in Figure 14 and detailed in Appendix 1.

![New Holland M135 tractor and D1010 baler](image)

**Figure 14** New Holland M135 tractor and D1010 baler

As illustrated in Figure 15, this particular model has 6 hinged panel guards that enclose PTO driven mechanisms:

- Guard No.1: front guard which encloses the PTO shaft(s) and flywheel;
- Guard Nos. 2 & 3: right hand (far side) upper and lower guards which enclose the packer and pickup drives & clutches and stuffer brake;
- Guard Nos. 4 & 5: left hand (near side) upper and lower guards which enclose the stuffer drive and clutch mechanism;
- Guard No. 6: top guard which houses the knotters and their associated driveline.
The front and upper side guards are fitted with gas struts, which operate through an over centre action, to both hold the guard closed and fully open as desired. A mechanical lock is also fitted to these main guard panels, which latches when the guard is closed and requires a tool (spanner or screwdriver) to unlock and open the guard. As supplied, neither of the lower side guards have a separate latch and are held shut by closing the lower guard first and then closing the upper guard onto an overlap section, which holds the lower guard closed until the upper guard is unlocked.

There are a number of other hinged panels on the baler, principally the twine box covers, but as these do not enclose any driven mechanism no locking system was fitted.

6.2 INTERLOCKING SYSTEM DESIGN

The general concept of the interlocking system design was to retain the existing guard panels of the target implement, but replace the manual locks with interlock switches, which, via an appropriate control system, would disengage the tractor PTO if a guard was not in place during machine operation.

A further hazard that is presented by the baler, and other implements which utilise a flywheel to smooth fluctuating power requirements, is the time the implement takes to run-down to standstill after the PTO is disengaged. As discussed in Section 4, this necessitates the use of guard locking interlock switches to prevent access to the mechanism during the rundown period. As the natural run-down time of the baler is variable, depending on internal loading, a motion sensor is also required in the guard locking control circuit, to ensure that the implement mechanism has come to rest before the guards are unlocked, allowing the guard panels to be opened.
Following a risk assessment and deliberation of the overall guard system functionality the following safety strategy was selected for this implement:

- Prevent the PTO from being engaged when any of the guards are not closed (and locked);
- Prevent any of the guards from being opened when the PTO is engaged;
- Immediately disengage the PTO driveline when a guard is opened during machine operation;
- Ensure the flywheel is at rest and the brake applied before guard access is enabled.

A review of specific manufacturers safety systems was carried out and a number of their safety matrix / product selection programs were utilised, an example of which is illustrated in Figure 16. These systems confirmed the need to use solenoid locking interlock switches in conjunction with appropriate safety relays, to provide a category 3 safety system appropriate for this level of hazard. The different requirements of interlocking system categories summarised in Table 3.

![Figure 16](image.png)

**Figure 16** Pilz interactive guide to safety product selection (Pilz)

As is typical of agricultural vehicles, the electrical systems of the tractor and baler used in this investigation were designed to function from a 12 V DC supply. All of the interlock switch manufacturers approached offered guard locking interlock switches, safety relays and system control units which operated on 110 / 230 V AC or 24 V AC / DC. Although some manufacturers stated that they might be able to produce 12 V DC “specials” in guard locking
interlock switches, it was decided to utilise a separate 24 V DC power supply for the safety
circuit in this application, to ensure access to the full range of industrial safety products.

To fulfil the requirements of the safety strategy it was necessary to use dual channel force
disconnected interlock switches / guard locking interlock switches, a dual channel monitoring
safety relay and an electronic stop motion detector. The products were selected from the
Guardmaster range as follows:

- Trojan 5 – GD2 tongue operated safety interlock switches for the lower side guards;
- TLS-3 – GD2 tongue operated safety interlock switches with guard locking for the
  front, upper side and top guards;
- MSR 12T dual channel monitoring safety relay to monitor safety switch outputs;
- CU2 electronic stop motion detector.

These components were fitted to the baler and are illustrated in Figures 17,18 and 19: full
component specifications are given in Appendix 2.

Figure 17 Typical location of Trojan interlock switch (1) and TLS-3 guard locking
interlock switch (2) for side guard assembly

A dual channel safety relay was used to monitor all of the interlock switches, with each of the
interlock switches primary and secondary safety circuits being connected in series to provide
two safety circuits, as detailed in the wiring diagram given in Appendix 3. As well as the two
sets of safety contacts, each interlock switch also contained a pair of auxiliary contacts, which
were used to provide a signal to an operator indicator panel, located inside the tractor cab. This
indicator panel, shown in Figure 20, was used to alert the operator to the status of each of the
guard panels, i.e. open or closed, enabling the operator to quickly locate the cause of any
interruption to the PTO drive arising from the safety system.
Figure 18  Guard locking interlock switch and mounting assembly for front guard

Figure 19  MSR 12T safety relay and CU2 controller located inside baler twine box
No suitable independent PTO clutch was located, prior to the interlock system implementation on this baler, which could accommodate the high torque / cyclical loading of the baler. The output of the safety relay was therefore “hard-wired” into the electronic control system of the tractor electro-hydraulic PTO clutch. Use of an existing interlock signal in the tractor’s PTO electronic control unit (ECU) ensured that the safety relay signal could not be overridden by the operator re-engaging the PTO from either the in-cab or fender-mounted PTO switches.

Since the construction of the demonstration interlock system Walterscheid have introduced a new range of safety clutches specifically for this type of application, an example of which is shown in Figure 21. The clutches are based on proven technologies (cut-out, friction and shearbolt) but can be actuated from an external source, including cable, hydraulic or electrical actuation options. However, the operational characteristics of the implement and interlock system would have to be carefully considered when fitting this type of independent clutch, to ensure suitable re-engagement criteria and the elimination of nuisance tripping where a shearbolt clutch was utilised.

To ensure that the baler mechanism had stopped prior to the solenoid guard locks being opened, a dual channel motion detector was also fitted to the baler drive, down stream of the overrun clutch. Two proximity sensors, highlighted in Figure 22, were fitted to the baler to monitor a cogwheel that was directly driven from the baler gearbox. The signal from these proximity sensors was monitored by the CU2 control unit (Figure 19), the output of which was connected in series with an interlock switch fitted to the manually operated flywheel brake, illustrated in Figure 23. This ensured that the baler mechanism was at rest and the flywheel brake applied before the guards were unlocked. Additionally, the tractor PTO could only be engaged if the flywheel brake was disengaged and all of the panel guards were in locked shut.
As the interlock switches would be subjected to the typical agricultural harvest environment during field testing i.e. dust, vibration, shock loads and possibly moisture, the enclosure rating had to be appropriate. All of the interlock switches were rated to IP67 (protected against dust ingress (totally) and water resistance between 15 cm – 1m immersion) and the control units, which were rated at IP20, were housed within an IP67 enclosure.

**Figure 21**  Artist’s impression of safety cut-out clutch (Walterscheid)

**Figure 22**  Detail of stop motion proximity sensors
Figure 23  Flywheel brake actuator and interlock switch
7 INTERLOCK SYSTEM TESTING

Following the installation of the interlock system components on the baler and tractor, the system was commissioned to check for wiring errors and logic faults. Initial tests were carried out in the laboratory, to ensure the system fulfilled the required safety strategy but did not impede the function of the baler, before proceeding to an in-field evaluation. This was to ensure that the hazard reduction, which could be achieved with this type of system, was balanced against any reduction in functionality of the baler and the possible incidence of false signals (and resultant downtime) that would lead to operator frustration, and possible rejection of the complete system.

A systematic laboratory testing programme was undertaken to determine if:-
- Any of the guards could be opened with the interlock system engaged;
- The PTO clutch would disengage / could not be re-engaged when one of the guards was open(ed) (guards were “opened” by using spare actuators in the unlocked guard switches);
- The PTO clutch would disengage / could not be re-engaged when the flywheel brake was on;
- The flywheel had come to rest and the brake was applied before the guard locks were energised to open.

This laboratory programme was successfully completed and a field evaluation of the system was then undertaken to determine if these industrial specification interlock components would withstand normal agricultural conditions.

The field tests were conducted by monitoring system performance during typical straw baling operations on SRI farmland and neighbouring commercial farms. The same testing procedure used in the laboratory was conducted prior to, and at the end of, each baling session and was also undertaken at regular intervals during each period of field operation.

The baler was used throughout the 2001 harvest season and approximately 1000 bales were produced with the interlock system engaged. A normal maintenance schedule was undertaken with the baler being blown down with compressed air and lubricated prior to each baling session. Typical harvest conditions were encountered with the atmosphere generally dry and dusty and the field surfaces ranging from smooth to rough and rutted. A normal range of forward speeds were used during the field evaluation and this resulted in the demonstration system being subjected to a range of vibration levels, shock loading, thermal stresses and high concentrations of atmospheric dust and straw.

The system functioned successfully throughout the field evaluation programme without producing any false trips during normal operation. However, on two occasions, after the guards had been opened during routine checking, the tractor PTO could not be re-engaged because one of the guard switch circuits was not completed. This was indicated by one green and one red light showing on the safety relay (Figure 21) even though no “guard open” signal was displayed on the indicator panel and all the guards were checked and found to be locked shut. Following investigation the cause was determined to be dust ingress into the guardlocking switch mechanism via the actuator slot. The dust ingress appeared to produce sufficient interference to the lock mechanism to leave one of the switch contacts within the solenoid locking mechanism open, even though the guard was physically locked. As with the guard switches, the locking mechanism contains dual circuit monitoring, which indicates status of the guard lock. As one of
the dual safety circuits was open, and the other closed, the interlock system status was registered
as unsafe, with the result that PTO clutch engagement was disabled by the safety system.

On each occasion that this occurred, the practical solution was to “blow down” the switch using
compressed air, after which full functionality was regained. This also highlighted that the
interlock switches and the guardlocking switches, contained within the guardlocking interlock
units, function at slightly different points of the actuator travel into the body of the unit. The
auxiliary contacts used to supply the indicator panel in the tractor cab are operated by the same
mechanism as the guard switches, whereas the actuator requires to be fully inserted before the
lock, and associated switches, function. This means that the in-cab indicator panel does not
register any fault that occurs on the locking circuit and so the current indicator system could not
be used to see which guardlocking switch was producing this type of fault. This could be
resolved by rewiring the indicator panel circuit to include the solenoid contacts in the locking
mechanism or by fitting a safety relay for each of the guard locking interlock switches used on
the implement.
8 DISCUSSION

The continuing developments in agricultural vehicle design have resulted in a general increase in comfort and hazard protection to afforded to operator. However, the agricultural accident statistics reviewed for this investigation suggest that contact with machinery has been a relatively constant factor in both fatalities and severe injuries in the recent past, and many of these accidents involve PTO driven implements. Although all powered mechanisms require some level of guarding against accidental contact, it remains possible for an agricultural operator to access hazardous areas of a PTO driven implement while the machine is still under power. This may be when attempting to clear a blockage from crop pick-up or conveyor, or by opening a hinged guard (using a key or tool) to inspect the enclosed mechanism. The PTO may have been deliberately left engaged by the operator to minimise downtime, or may have been overlooked with the pressure to “get the job done”, but in either case the potential consequences are severe. Obviously the use of some form of safety interlock system between the access route to these hazard areas and the PTO driveline engagement appears desirable and offers a considerable reduction to the potential for operator injury.

The review of current tractor specifications has highlighted that, although electro-hydraulic PTO clutch engagement is the most common, both mechanical and hydro-mechanical systems are still available and form a significant part of the UK tractor fleet. This indicates that, for a safety interlock system to be universally applicable across the tractor and implements in current use, an independent PTO driveline clutch would be required as part of the interlock system. Also, irrespective of the position of the PTO driveline clutch, a control interlocking system is required (where a control unit monitors the interlock switches and also has authority over the power interruption device) for this generic mix of mechanical power transmission and electrical guard monitoring. Although in the demonstration system constructed, the tractor’s existing electro-hydraulic PTO clutch was utilised as the driveline interruption device, the operation of the interlock system remains the same as a system with an independent driveline clutch.

To be fully applicable to the UK tractor fleet an independent clutch would be required and this would result in a relatively self-contained interlock system, assuming that this clutch is mounted on the implement. Although the interlock system would still require a power supply from the tractor, it would alleviate the need for a critical electrical connection between the implement and a tractor-mounted clutch. However, in this implementation, the situation could arise where the power is disengaged to the implement mechanism by the implement-mounted clutch but the PTO shaft between the tractor and safety system clutch is still rotating. Also, although the use of an independent implement-mounted clutch would enable an interlocking system to be universally applicable a clutch would be required for each implement application of the system with the resultant cost implications.

The imminent introduction of the ISOBUS (CAN-bus) system of communication between tractor and implement control modules will offer another option for safety interlock systems on new vehicles. In this case a guard interlock system would utilise the tractor PTO clutch as a driveline interrupter, but the power supply to the interlock system and the PTO clutch control signals would be via a single connector at the tractor / implement interface. This would simplify the connections to be made when the implement is attached and, because implement control would also be via the same CAN-bus socket, it reduces the possibility that the operator would compromise the safety system when attaching the implement by missing and/or damaging connections.
The demonstration safety interlocking system, which was constructed and evaluated during this investigation, utilised standard industrial interlocking components. Guard interlocks have been widely used in industrial situations for many years and there is a wide range of components that may be applicable for agricultural field machinery. In general the components used proved to be adequate for purpose with no loss of safety functionality during the field evaluation, although there was some loss of baler functionality due to guard lock malfunction. This type of malfunction would have been highly frustrating to a commercial operator and requires resolution for the system to be commercially acceptable.
9 CONCLUSIONS

The overall objective of this investigation was to undertake research leading to the development of a prototype guard interlocking system, suitable for use with a wide range of PTO (power take-off) driven agricultural machinery in the UK. The authors have drawn the following conclusions from this investigation:

- The percentage of injuries due to contact with machinery has remained relatively constant over the last 6 years;
- There is a trend towards fewer but larger (and more sophisticated) implements, and although not the most numerous implements within the UK fleet, potato & forage harvesters and balers offer the highest potential risk of injury to operators;
- Although overall tractor sales volumes are declining, the average engine power of new tractors is steadily increasing and, in general, larger tractors tend to be of higher specification, incorporation increasing levels of electronic control;
- Electro-hydraulic PTO engagement is currently the most common system present on tractors sold in the UK. However, a significant proportion of the total UK tractor fleet does not use electro-hydraulic PTO engagement;
- Guard interlocking of PTO driven machines could help prevent accidents but an independent driveline interruption device would be required to enable the technique to be universally applicable to the UK tractor fleet;
- The imminent introduction of an ISO standard for CAN-bus communication protocols (ISO 11783) between tractors and implements could be utilised to introduce PTO interlocking systems on new tractors and implements;
- There is a wide range of industrial safety products available, with suitable levels of enclosure rating, which may be utilised on agricultural implements;
- Guard-locking interlock switches, motion detection systems and/or driveline brakes may be required on PTO driven machines that have a run-down period following power isolation;
- The interlock system components utilised on the demonstration implement were selected from commonly available industrial specification safety components, but a 24 V DC power supply was required, in addition to the 12 V DC supply available from the tractor, in order to enable full utilisation the standard component range;
- Initial functionality tests and an extensive laboratory and field evaluation programme were successfully undertaken on the demonstration PTO interlocking system, which maintained its safety functionality at all times. However, some “nuisance tripping” was produced following routine inspection and this issue needs to be addressed to ensure commercial operator acceptance of this type of interlock system;
- Although a big square baler was selected as the most suitable implement on which to install the demonstration interlock system, the results would be equally applicable to other PTO driven implements with hinged guard panels.
10 REFERENCES


APPENDIX 1  NH D1010 BALER SPECIFICATIONS

Make:- New Holland
Model:- D1010  CropCutter

Weight:- 6490 kg (empty)
          6720 kg (with twine boxes loaded)
Tyres:- 6.00/50 - 22.5 - 8 PR

Pickup
Width:- 1.782 m (1.968 m incl. deflectors)
Diameter:- 270 mm
No. of tines:- 56 (double)
Tine spacing:- 66 mm
No. of bars:- 4
Reel speed:- 148 rpm
Drive:- chain
Protection:- slip & overrun clutch
Lift mechanism:- hydraulic

Feeder system
Packer system:- 3 forks, 6 double tines
Rotational speed:- 172 rpm
Drive:- chain
Protection:- slip clutch set at 4000 N.m

Pre-compression system
Pre-compression chamber:- splayed profile, anti-friction floor
Crop flowrate compensation:- automatic charge sensing door (operating against adjustable tension spring) engages stuffer clutch
fork-type with 6 tines
Stuffer assembly:- up to 42 cycles per min.
Speed:-
Drive:- chain
Protection:- shearbolt

Bale chamber & plunger
Plunger speed:- 42 strokes per min
Length of stroke:- 710 mm
Mounting:- 4 carrier and 2 guide roller bearings
Chamber size:- 800 mm wide
          870 mm high
          2540 long
Bale density control:- automatic - electro-hydraulic, adjustable from tractor seat
<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bale size</td>
<td>800 mm wide 900 mm high 1200 - 2500 mm long</td>
</tr>
<tr>
<td><strong>Tying mechanism</strong></td>
<td></td>
</tr>
<tr>
<td>Knotters</td>
<td>double knot type</td>
</tr>
<tr>
<td>No. of knotters</td>
<td>4</td>
</tr>
<tr>
<td>Twine spacing</td>
<td>172 mm</td>
</tr>
<tr>
<td>Knotter / needle drive</td>
<td>bevel gears &amp; shaft</td>
</tr>
<tr>
<td>Protection</td>
<td>mechanical linkage, timed with plunger movement</td>
</tr>
<tr>
<td>Knotter performance indicators</td>
<td>electronic (audio-visual) &amp; mechanical flags</td>
</tr>
<tr>
<td>Twine capacity</td>
<td>24 balls + 2 3 balls per knotter, 3 balls per needle</td>
</tr>
<tr>
<td>Twine type</td>
<td>heavy-duty plastic (130 m/kg)</td>
</tr>
<tr>
<td><strong>Main drive</strong></td>
<td></td>
</tr>
<tr>
<td>P.T.O. speed</td>
<td>1000 rpm</td>
</tr>
<tr>
<td>Driveline protection</td>
<td>shearbolt and overrun clutch &amp; (non-adjustable) slip clutch (set at 1200 N.m)</td>
</tr>
<tr>
<td>Flywheel</td>
<td>720 mm diameter</td>
</tr>
<tr>
<td>Flywheel brake</td>
<td>220 kg mass</td>
</tr>
<tr>
<td>Gearbox</td>
<td>direct-acting, lever-operated band type</td>
</tr>
<tr>
<td></td>
<td>spiral bevel and spur reduction gear sets, enclosed in oil bath</td>
</tr>
<tr>
<td><strong>Bale Command functions</strong></td>
<td></td>
</tr>
<tr>
<td>Operating aids</td>
<td>monitoring of:</td>
</tr>
<tr>
<td></td>
<td>plunger loading</td>
</tr>
<tr>
<td></td>
<td>crop feeding</td>
</tr>
<tr>
<td></td>
<td>knotter performance</td>
</tr>
<tr>
<td></td>
<td>knotter cycle indication</td>
</tr>
<tr>
<td></td>
<td>daily bale count display</td>
</tr>
<tr>
<td></td>
<td>total bale count display</td>
</tr>
<tr>
<td>Baler control</td>
<td>sensing and control of bale density, by monitoring</td>
</tr>
<tr>
<td></td>
<td>of compression loading on baler plunger</td>
</tr>
<tr>
<td>Alarms</td>
<td>flywheel brake engaged</td>
</tr>
<tr>
<td></td>
<td>packer / pickup drive slippage</td>
</tr>
<tr>
<td></td>
<td>knotter mis-ties</td>
</tr>
<tr>
<td></td>
<td>plunger load sensor failure</td>
</tr>
<tr>
<td></td>
<td>stuffer drive shearbolt failure</td>
</tr>
<tr>
<td><strong>Tractor requirements</strong></td>
<td></td>
</tr>
<tr>
<td>Minimum weight</td>
<td>6000 kg</td>
</tr>
<tr>
<td>Minimum power</td>
<td>80 kW (110 hp) at P.T.O.</td>
</tr>
<tr>
<td>P.T.O. speed</td>
<td>1000 rpm</td>
</tr>
<tr>
<td>P.T.O. shaft</td>
<td>1-3/8” - 21 spline</td>
</tr>
</tbody>
</table>
# APPENDIX 2  INTERLOCKING SYSTEM COMPONENTS

## Trojan 5 - GD2
- Universal tongue operated safety interlock switch

## TLS - GD2
- Compact tongue operated safety interlock switch with guard locking

## MSR12T
- Dual channel monitoring safety relay, auto/manual reset

## CU2
- Electronic stop motion detector

<table>
<thead>
<tr>
<th>Part No.</th>
<th>Type Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>IP67</td>
</tr>
<tr>
<td>3 x M20 or Pg13.5</td>
<td>3 x Conduit Entry</td>
</tr>
<tr>
<td>2 x M5</td>
<td>4 x M5</td>
</tr>
<tr>
<td>AC 15 U/e</td>
<td>AC 15 U/e</td>
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<tr>
<td>500V 1A, 250V 2A, 100V 5A</td>
<td>250V AC, 4A</td>
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<tr>
<td>d.c. 250V 0.5A, 24V 2A</td>
<td>30V DC, 2A</td>
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<table>
<thead>
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<th>Part No.</th>
<th>Type Description</th>
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<td>160</td>
<td>EMC</td>
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</table>

## Metal end cap, plug-in connector
- Rotatable head, 4 pin key entries, locking force 2000N
- fallsafe internal monitoring, monitors contacts + 2 safety inputs, auto reset
- Uses two inputs (proximity switches) to monitor rotation of metal parts of machine

<table>
<thead>
<tr>
<th>Part No.</th>
<th>Type Description</th>
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<tr>
<td>95 x 50 x 32mm</td>
<td>130 x 92 x 37mm</td>
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<tr>
<td>73 x 45 x 120mm</td>
<td>73 x 45 x 120mm</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Type</th>
<th>Part No.</th>
<th>Type</th>
<th>Part No.</th>
<th>Type</th>
<th>Part No.</th>
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<tbody>
<tr>
<td>Break before make contacts:</td>
<td></td>
<td>Order actuators separately:</td>
<td>14VAC/DC</td>
<td>230VAC</td>
<td>24V AC/DC</td>
</tr>
<tr>
<td>MSD = Make before break contacts:</td>
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<td>Order actuators separately:</td>
<td>110VAC</td>
<td>230VAC</td>
<td>110/230V AC</td>
</tr>
<tr>
<td>MSD, limit entry (BP):</td>
<td></td>
<td>Order actuators separately:</td>
<td>110/230V AC</td>
<td>230VAC</td>
<td>110/230V AC</td>
</tr>
<tr>
<td>Pgl, front entry (BP):</td>
<td></td>
<td>Order actuators separately:</td>
<td>110/230V AC</td>
<td>230VAC</td>
<td>Sensors (1 x NPN &amp; 1 x PNP)</td>
</tr>
<tr>
<td>Msd, reverse entry (BP):</td>
<td></td>
<td>Order actuators separately:</td>
<td>110/230V AC</td>
<td>230VAC</td>
<td>24V AC/DC, Unit and sensors</td>
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<tr>
<td>Pgl, reverse entry (BP):</td>
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<td>Order actuators separately:</td>
<td>110/230V AC</td>
<td>230VAC</td>
<td>110/230V AC, Unit and sensors</td>
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<td>Standard actuator:</td>
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<td>Lock-off sliding actuator:</td>
<td></td>
<td>Actuators, accessories, etc., refer to TLS-1 &amp; 2: Actuators, accessories, etc., refer to TLS-1 &amp; 2:</td>
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BALE CONTROL BOX

TBA

MSRI2T MONITOR

CU2 MOTION DETECTOR

TBB

ALA RELAY

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