Health and Safety Executive

Research into the effectiveness of safety bar devices fitted to satellite arm bale wrapping machines

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Research Report

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Research into the effectiveness of safety bar devices fitted to satellite arm bale wrapping machines

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This work identified a wide range of satellite arm bale wrappers available within the UK. Testing of these wrappers indicated that, as supplied, a large proportion of these wrappers have safety bar devices that do not perform in the manner desired. This is because in many cases, following the triggering of the safety bar, the rotating dispenser arms were not brought to an abrupt enough stop. This resulted in the dispenser arms passing the point at which the safety bar had been triggered, hence introducing the possibility of the dispenser arm striking whatever/whoever had triggered the safety bar. It is therefore apparent that bale wrapper manufacturers need to address this issue and develop solutions to improve the performance of the safety bar devices.

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KEY MESSAGES

- This work identified a wide range of satellite arm bale wrappers available within the UK. Testing of these wrappers indicated that, as supplied, a large proportion of these wrappers have safety bar devices that do not perform in the manner desired. This is because in many cases, following the triggering of the safety bar, the rotating dispenser arms were not brought to an abrupt enough stop. This resulted in the dispenser arms passing the point at which the safety bar had been triggered, hence introducing the possibility of the dispenser arm striking whatever/whoever had triggered the safety bar. It is therefore apparent that bale wrapper manufacturers need to address this issue and develop solutions to improve the performance of the safety bar devices.

- Two main methods of stopping the flow of hydraulic fluid to the motor powering the rotation of the wrapper arms (and hence stopping the arms) were identified. Both methods relied upon the movement of the safety bar back towards the dispenser arm. This movement was either transferred via a mechanical link to a valve actuator, cutting the flow of fluid to the motor, or detected by an electric switch (which would subsequently lead to the fluid supply being cut by valve movement under electrical control). Neither method showed any significant performance advantage over the other.

- During testing it was found that the stopping distance of the wrapper arms, following activation of the safety bar, could be greatly reduced by reducing the rotational speed of the wrapper arms, although reducing the rotational speed of the wrappers will increase the cycle time for wrapping a bale. However it will, if manufacturers cannot find alternative solutions to improve stopping distances, ensure the safety system operates as desired and will reduce the risk of injury.

- With the aid of an ergonomics review of the speed of movement of individuals a relationship was developed to allow a maximum spacing between the safety bar and dispenser arm during normal operation to be found. This suggested maximum spacing should be implemented into the design of bale wrappers to minimise the risk of an individual entering the space between the safety bar and dispenser arms during operation of the machine. If this were to happen then there is the likelihood that the individual would be struck by the dispenser arm, without triggering the safety mechanism. This maximum spacing is dependant on both the speed and diameter of rotation of the wrapper arms and given by:

$$x = 2r\left(Sin\frac{36N}{60}\right)$$

x = Spacing between safety bar and dispenser arm (m)
r = Radius of rotation (m)
N = Speed of rotation (rpm)

EXECUTIVE SUMMARY

Background

The design of satellite arm bale wrapping machines is that, normally two dispenser arms (although some models only have one arm), holding rolls of plastic film rotate around a bale in order to wrap the bale in the plastic film. The rotation of the arms is controlled by a centrally located hydraulically powered motor. As these arms rotate at a large diameter (up to 3.5m) at speeds of up to 35rpm and have a significant mass there is a potential for harm to be caused by an individual being struck by one of these arms.

So mounted to each arm, and held at a set distance in front of the arm, is a safety bar. If a safety bar hits an object (such as a person) the intention is that the arms will cease rotating in a short enough period that the arm associated with that safety bar will not pass the position of the point of contact between the safety bar and the object. If the arm were to pass this point there is the potential for the arm to hit that object.

A fatality occurred in Shropshire in 2009, in which an individual was apparently struck by the rotating arms of a bale wrapping machine. In this incident it was evident that the safety bar system fitted to these rotating arms had not operated as desired, and preliminary testing on further machines raised concerns that this may be a more widespread issue.

Objectives

The Health and Safety Laboratory (HSL) were requested to develop a test rig and method and to perform tests on a range of bale wrappers available within the UK.

In total six manufacturers of bale wrappers were contacted and asked to providence assistance by making machines available for testing. Four of these were able to provide machines for testing within the timescales of the project.

The purpose of the testing was to measure the distance travelled by the rotating arms of the bale wrapping machines, following the activation of the safety bar to see whether or not the desired stopping criteria was met.

It was necessary for the test rig developed at HSL to be portable; in order to allow it to be taken to sites across the UK in order to perform the required testing.

HSL were also asked to recommend a maximum allowable spacing between the safety bar and dispenser arm. This is to limit the risk of an individual entering this space whilst the arms are rotating and potentially being struck by the dispenser arm without triggering the safety bar.

Main Findings

In total eight separate bale wrappers (six different models from four different manufacturers) were tested. Of these eight machines only two successfully stopped the rotation of the dispenser arms in a short enough period such that they did not pass the position of initial contact with the safety bar, when set on their ‘factory’, as supplied settings.

Of the remaining six machines modifications made by engineers during the testing sessions enabled three more of them to reach the required criteria; the modification which had the greatest impact on decreasing the stopping distances was a reduction of the speed of rotation of the arms. Further improvements in stopping distance were also achieved on some machines by modifying the pressure settings of the hydraulic motor and changing the sensitivity settings of electrical switches that monitored movement of the safety bars. An example of the effects of these modifications is that on the Machine B1 a reduction of the rotational speed from 35rpm to 29rpm along with a modification of the pressure settings reduced the stopping distances from around 1000mm to approximately 600mm.

This research also considered the size of the gap between the safety bar and dispenser arm. There are obvious benefits to a manufacturer of making this gap as large as possible as doing so will give a greater distance in which to stop the arm rotation following the triggering of the safety bar. However if this gap becomes too large it introduces the potential for an individual to enter this gap and be struck by the dispenser arm without triggering the safety bar. Therefore using ergonomic data on the speed of movement of individuals in varying situations, ie. walking and standing up, a relationship between the speed and diameter of rotation of the dispenser arms, and the maximum permissible gap between the safety bar and dispenser arm was formed. It was determined that the greater the speed of rotation and the larger the diameter of rotation, the greater the permissible gap between safety bar and dispenser arm was. This is because increasing either of these increases the relative speed of the dispenser arms/safety bar, hence, given a set time for an individual to move into a position of danger the arms will move further in this time. For example for a wrapper with an arm diameter of 3m, at 20rpm the maximum gap would be 0.62m and at 30rpm this would be 0.93m.

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1 INTRODUCTION

Satellite arm bale wrapping machines are used to wrap forage in layers of plastic film for the production of silage or for weather protection. Their general operation involves either one or two ‘dispenser arms’ that hold rolls of plastic film rotating around the outside of a centrally held bale. In doing so the bale is wrapped in the plastic film. Accidents have occurred over recent years in which individuals have been struck by these rotating dispenser arms, including a fatal accident that occurred in Shropshire in 2009. This fatality has led to questions being asked about the effectiveness of the safety mechanisms fitted to these machines which are intended to stop the rotation of the dispenser arms if a safety bar, mounted in front of the dispenser arms, strikes an object/individual.

Preliminary testing performed by HSE inspectors indicated that, on some machines, the dispenser arm would pass the point at which the safety bar made contact with an object before coming to a rest (i.e. if the safety bar were to strike an individual the dispenser arm would stop at a point past where the individual was located and would therefore potentially make contact with that individual). However, at the time of these preliminary tests there was no set test method or rig available. Therefore HSL were requested by HSE to develop such a test rig and method, and then carry out testing on a range of machines from varying manufacturers that supply within the UK. Hence determining the scope of the perceived issue that, on many machines, the dispenser arms did not stop rotating quick enough for the safety device to be effective could be ascertained. HSL were also requested to perform an ergonomics review of the safety bar/dispenser arm arrangement and asked to suggest a maximum allowable distance between the safety bar and dispenser arm, such that the safety arm would remain effective whilst it would not be possible for an individual to pass into the gap between the safety bar and dispenser arm, whilst the arms are rotating, and therefore potentially being struck by the dispenser arm without triggering the safety bar.

Six of the largest manufacturers that supply bale wrapper machines to the UK market were contacted and requested to assist in the test program by making available machines for testing. At the time of compiling this report four of these had made machines available for testing.

2 DESCRIPTION OF SATELLITE ARM BALE WRAPPING MACHINES

2.1 SATELLITE ARM BALE WRAPPING MACHINES

Satellite arm bale wrapping machines are used to wrap bales of forage in layers of thin plastic film for the production of silage or for weather protection. They are commonly available as both stand-alone units or as part of a combination baling and wrapping unit. The basic design of the wrapping mechanism of all such machines encountered during this project was broadly similar with the bale being held centrally in the machine whilst either one or two satellite arms, holding dispenser rolls of film, rotate around the bale. The arms rotate about a central hub, containing a hydraulic motor that powers the rotation, mounted above the position of the bale. As these arms rotate the bale is turned such that the entire bale is wrapped in film. Once the bale is wrapped it is dispensed off the wrapper machine in preparation for the next bale which is either pick up by a conveyor, or fed in directly from a baling unit (on combination machines). The wrappers encountered were all tractor mountable and hydraulically powered, with the wrappers taking their power from the power take-off (PTO) of an attached tractor. An example of a bale wrapper is shown in Figure 1.

Static and fully mounted machines were not tested in this study but the principles of the satellite arm operation and safety devices are equally applicable.

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Figure 1 Bale wrapper overview

2.2 SAFETY BAR DEVICE

The dispenser arms on bale wrapping machines rotate at a fixed diameter (generally between 2.5m and 3.5m) and at speeds of between 20 and 35rpm. These relatively large diameters of rotation mean that the path of the dispenser arms often takes them out of the confines of the wrapping machines and into areas easily accessible by persons (i.e. as the arms rotate they pass out beyond the sides or rear of the machine). This, combined with the mass and speed at which the arms travel, means that there is potential for harm to be caused to an individual being struck by the rotating dispenser arms. Therefore mounted to the dispenser arms are safety bars, see Figure 1.

The purpose of the safety bars is that if they strike an object (i.e. person) the rotation of the dispenser arms will be stopped. The intention is that the arms will stop rotating in a short enough period such that the dispenser arm will not pass the point at which the safety bar was first triggered (i.e. the position of the object/person being struck). This is to prevent the possibility of the moving dispenser arm hitting that object/person and causing potential damage or harm. On all bale wrappers encountered during this project, the safety bars consisted of a length of aluminium tubing, bent into shape such that they hung at a set distance vertically in front of the dispenser arms. The vertical lengths of the safety bars that hung in front of the dispenser arms were protected with a foam sleeve to cushion any impact of objects with them, reducing the potential for the safety bar itself to cause injury or damage. They were mounted to the main arms via sprung hinge units such that when they struck an object the safety bars would move back towards the dispenser arms. It is this movement of the safety bar, back towards the dispenser arm, that initiates the process of the rotation of the dispenser arms being stopped. The spring in the hinge unit is used to hold the safety bar in position during normal operation and provides a degree of resistance to the movement of the safety bar so as to prevent ‘false’ activations that could be caused for example by jolting of the machine resulting from driving it over uneven ground. However it has to be ensured that the spring is not so stiff that the safety bar won’t activate on striking an object. During testing the static force required to move the safety bars was measured using a hand held force gauge.

The initial distance between the front of the safety bar and the leading edge of the dispenser arm generally varied between 0.4 and 1.0m on the bale wrappers encountered during this project. The significance of this distance is discussed further in Section 6 of this report.

There were two general methods encountered for the activation/movement of the safety bar stopping the rotation of the arms. This was either a mechanical link from the safety bar, which, upon activation of the safety bar, shut off the hydraulic supply to the motor via movement of a valve. Alternatively the ‘shut-off’ of the hydraulic supply was controlled electronically via a switch that detected movement of the safety bar.

2.3 MODELS SUPPLIED WITHIN THE UK

At the outset of this project a search of the market was performed in order to identify the main brands and models of satellite arm bale wrappers available in the UK. A summary of these is shown below in Table 1, it should be noted that this list is not exhaustive.

Table 1 Bale wrappers available in the UK

Brand	***Model***	***Company details***
Claas	Rollant 355 Uniwrap	CLAAS U. K. Ltd. Saxham Business Park Saxham – Bury St. Edmunds Suffolk IP28 6QZ
John Deere	744	John Deere Ltd. Harby Road Langar Nottingham NG13 9HT
Kuhn	FBP2135 Bale Pack RW1200 RW1800	Kuhn Farm Machinery (UK) Ltd Stafford Park 7 Telford Shropshire TF3 3BQ
Kverneland	7650 7230 7664	Kverneland Group UK Ltd. Walkers Lane Lea Green St. Helens Merseyside WA9 4AF
Goweil (supplied by Lely in UK)	G4020 G5020	Göweil Maschinenbau GmbH Davidschlag 11 A-4202 Kirchschlag bei Linz Austria
Lely	Welger RP235 Attis HR 16	Lely UK Ltd. Station Road St Neots Cambridgeshire PE19 1QH
McHale	998 HS2000	McHale Engineering Limited Castlebar Road Ballinrobe Co. Mayo, Ireland.
Tanco	1400 1814	Tanco Autowrap Limited Royal Oak Road Bagenalstown County Carlow, Ireland
Vicon	RF2235 Bale Pack RV2160 Bale Pack RV2190 Bale Pack BW1850 BW1200	Kverneland Group UK Ltd. Walkers Lane Lea Green St. Helens Merseyside WA9 4AF

3 DEVELOPMENT OF TEST RIG AND METHOD

3.1 THE NEED FOR A TEST RIG

At the outset of the project there was no known standard test rig available that allowed the reliable and repeated testing of the effectiveness of the safety bar and stopping mechanisms of bale wrapping machines. Therefore one of the main requirements of this project was to develop such a rig.

3.2 TEST RIG REQUIREMENTS

In order to be effective the test rig developed to perform the tests needed to meet a number of requirements, these are summarised below:

~ To trigger the safety bar at a known point

~ To allow measurements of the degree of movement of the dispenser arm in relation to the initial trigger point of the safety bar

~ To allow repeatable tests

~ To be able to be deployed into the path of the safety bar without otherwise interfering with the movement of the wrapper

~ To not interfere with the stopping distance of the dispenser arms once the safety bar has been triggered

~ To be easily transportable to allow testing at various sites

~ To be adjustable such that it could be used on all models of bale wrapper encountered

~ To be easy to operate and take readings

~ To be robust

~ To be safe to operate

3.3 TEST RIG DESIGN AND OPERATION

The test rig developed at HSL is shown in Figure 2.

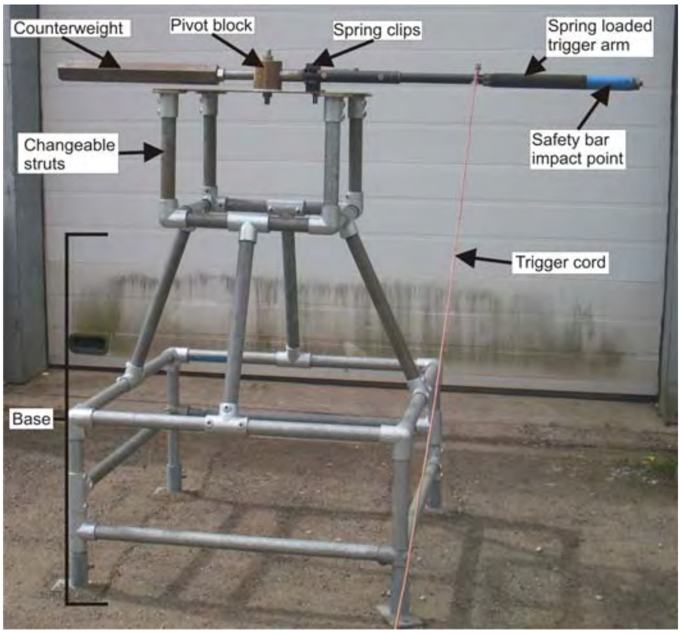

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Figure 2 Test rig

The test rig consists of a $1m^2$ base constructed from steel tubing connected with Kee-Klamp quick connectors to allow it to be easily broken down into modular units for transportation and then re-assembly at the test site. Mounted to the base unit, via four vertical struts, is a 5mm steel plate to which the safety bar trigger mechanism is mounted. To allow adjustability to the height of the trigger arm different lengths of these vertical struts were produced, allowing activation of the wrapper safety bars at heights of between 1.4-1.7m as required. The safety bar trigger arm consists of a spring loaded rod, which when activated, by pulling on a cord attached to a retaining bolt, extends into the path of the safety bar. This is illustrated in Figure 3. This spring loaded rod is mounted via a central pivot block and is counter-weighted to allow balanced rotation when extended.

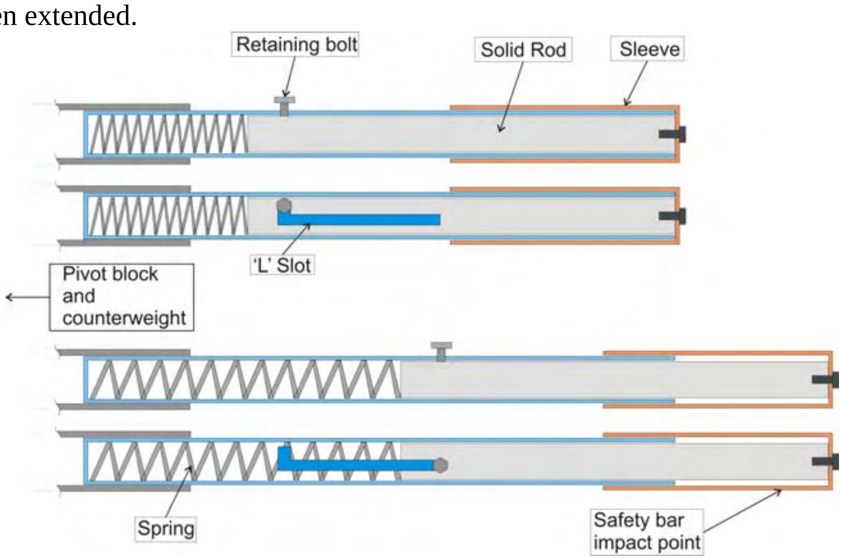


Figure 3 Operation of the spring loaded trigger arm

The central pivot block sits on a nylon disc and is affixed to the steel plate by a length of 32mm bar, threaded at either end – the tightening of the nuts on either end of this bar allows the adjustment of the freedom of movement of the pivot unit. During testing the tightening torque of these nuts is set such that there is sufficient resistance in the trigger units' rotation to activate the safety bar, but such that following the impact of the safety bar it will rotate away from the oncoming dispenser arm such that it doesn't provide any resistance which would assist in slowing the dispenser arm down (future improvements to the test procedure could include research to find a defined value of force/tightening torque desired to achieve this). This is illustrated in Figure 4.

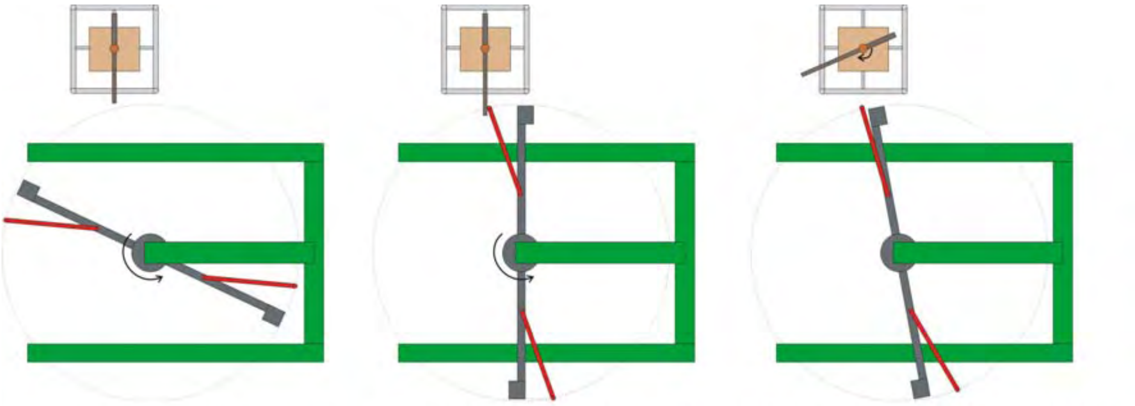


Figure 4 Operation of test rig

Also mounted to the steel plate are a set of spring clips which hold the trigger arm in place prior to the impact of the safety bar. These clips also then allow, following the test, the trigger arm to be replaced into the same position it was in when it triggered the safety bar.

A rectangular foot plate was fitted at each of the four corners, this plate was drilled with holes to allow the rig to be pegged into soft ground if required. However all testing performed by HSL was performed on concrete flooring, in these cases rubber sheeting was placed under each foot of the rig to reduce the risk of the rig slipping on the floor during testing. Strips of coloured tape were used to mark the position of the test rig feet to allow checks for any movement of the rig during testing to be made.

3.4 TEST METHOD

During the testing performed by HSL the following procedure was used:

1. The diameter of rotation of the wrappers' dispenser arms and the initial distance between the safety bar and dispenser arm were measured.

2. The wrapper was run through a standard cycle and a measure of the speed of rotation (in rpm) was made by timing the time taken for a certain number of rotations.

3. The rig was positioned such that the trigger arm, when in its set position, was perpendicular to the direction of travel of the wrappers safety bar at the intended impact point.

4. Once the rig was in place the trigger arm was extended into its impact position and aligned with the wrapper's safety bar such that the impact point could be marked on both the safety bar and the trigger arm.

5. The trigger arm was reset into its starting position, with rod retracted and held in the spring clips.

6. The wrapper cycle was started (or placed into manual 'free' rotate mode if available) and the arms allowed to rotate for a minimum of two complete revolutions to allow the arms to reach full speed.

7. The trigger cord was pulled at the appropriate time to deploy the arm into the path of the required safety bar.

8. Following activation of the safety bar, and subsequent stopping of the wrapper arms the wrapper safety bar was re-set and the trigger arm returned to its position before the impact of the safety bar, ie. being held by the spring clips.

9. The linear distance between the impact point on the safety bar and the impact point on the trigger arm was measured, see Figure 5.

10. This process (steps 5 to 9) was carried out five times on each safety bar on machines with two dispenser arms (if machines with a single dispenser arm had been encountered this process would have been carried out ten times on that single arm). The position of the rig was marked on the floor such that checks could be made to see whether the rig had moved during testing, and to aid in re-positioning if required. If the rig or wrapper had moved during a test the position of the impact points would have been re-marked.

11. The maximum, minimum and mean distances measured between the two impact points after each test are compared to the initial distance between the safety bar and dispenser arm to establish whether or not the dispenser arms stop rotating soon enough after the activation of the safety bar not to pass the initial impact point. The linear distance between the two points, and the measurement of the diameter of rotation could also be used to calculate the angle rotated following activation of the safety bar, see Figure 6.

Note: Testing should be carried out with full rolls of dispenser film fitted to the dispenser arms to provide the maximum angular momentum (i.e. worst case scenario) during testing.

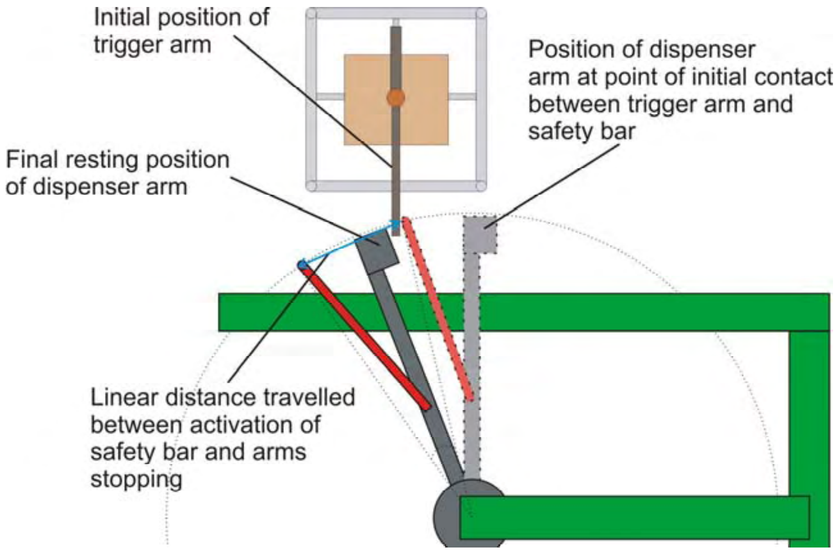
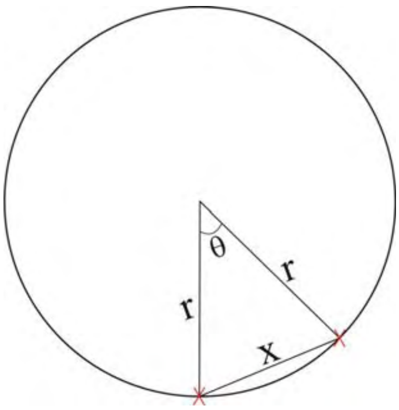


Figure 5 Schematic of test measurements



$$\theta = \arccos\left(\frac{r^2 + r^2 - x^2}{2r^2}\right)$$

$$\theta = \cos^{-1}\left(\frac{2r^2 - x^2}{2r^2}\right)$$

Figure 6 Calculating the stopping angle of rotation

4 TESTING AND RESULTS

4.1 MANUFACTURER A

The testing of two bale wrappers produced by Manufacturer A was carried out on the 24th March 2010. These were designated as wrappers A1 and A2.

The safety bar devices on these two machines operated in the same manner. Both safety bars were connected via a wire cable to a ‘flip-flop’ bar that is held in place under the centre of the motor hub by the two wire cables (one from each safety bar). When the safety bars are opened and away from the dispenser arms (as in normal operation) the arrangement is such that the wire cable between the safety bar and ‘flip-flop’ bar is under tension. Whilst both cables are under tension the ‘flip-flop’ bar is held up against a valve actuator. If tension in either cable is lost, as happens when the safety bar is activated and moved towards the dispenser arm, the ‘flip-flop’ bar drops causing the valve to shut, cutting the hydraulic supply to the motor. This arrangement is shown in Figure 7.

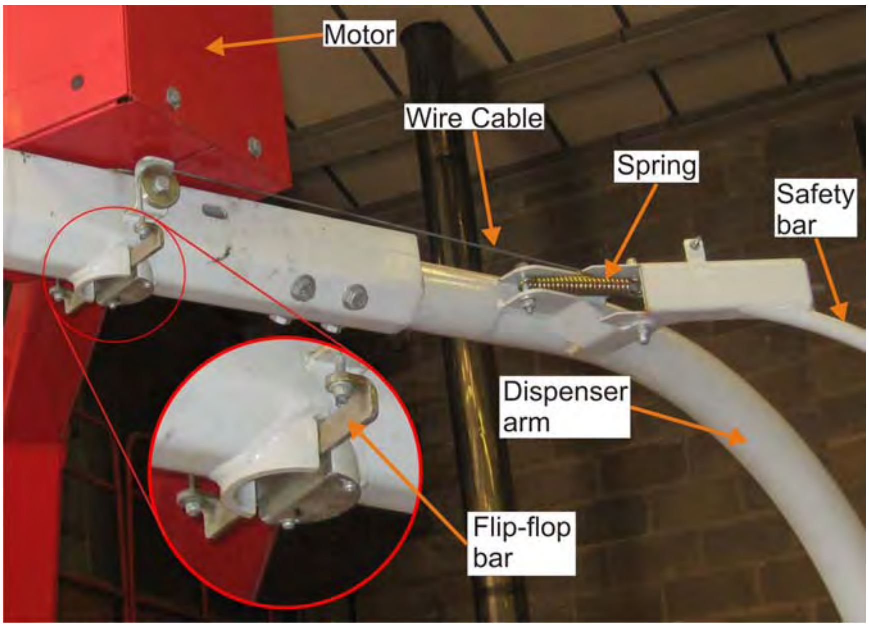


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Figure 7 Safety bar mechanism on Manufacturer A wrappers

The initial linear gap between the leading edge of the safety bar and that of the dispenser arm was nominally 420mm on A1 and 450mm on A2. So these are the distances within which it is desirable for the dispenser arms to have stopped rotating following initial activation of the safety bar in order that the dispenser arms did not pass this point of initial contact. These distances relate to a maximum arm rotation of 18^o on A1 and 15^o on A2 following activation of the safety bar before the leading edge of the dispenser arm will pass the point of initial contact of an object with the safety bar. The test results for Manufacturer A wrappers are shown summarised in Table 2. During these tests a calibrated hand-held Mecmesin force gauge was also used to measure the force required to activate the safety bars whilst the arms were stationary.

Table 2 Summary of results from testing of Manufacturer A bale wrappers

	A1	***A2***
Arm diameter	2660mm	3450mm
Speed of rotation	31rpm	28.5rpm
Distance from safety bar to dispenser arm	420mm	450mm
Minimum stopping distance	490mm	1100mm
Maximum stopping distance	530mm	1150mm
Mean stopping distance	510mm	1126mm
Required maximum angle of rotation to stop	18^o	15^o
Minimum angle of rotation to stop	21.2^o	37.2^o
Maximum angle of rotation to stop	23.0^o	38.9^o
Mean angle of rotation to stop	22.1^o	38.1^o
Mean safety bar activation force	70.6N	79.7N

4.2 MANUFACTURER B

The testing of two further bale wrappers was carried out on the 31st March 2010. The wrappers tested were designated as B1 and B2.

The safety bar device of the these wrappers operates using an electrically powered limit switch positioned against the safety bar mount (which moves together with the safety bar) such that it detects movement of the safety bar, see Figure 8. When movement of the safety bar is detected by this switch a valve is closed, cutting the hydraulic supply to the motor, hence the motor stops and the arms will cease rotating.

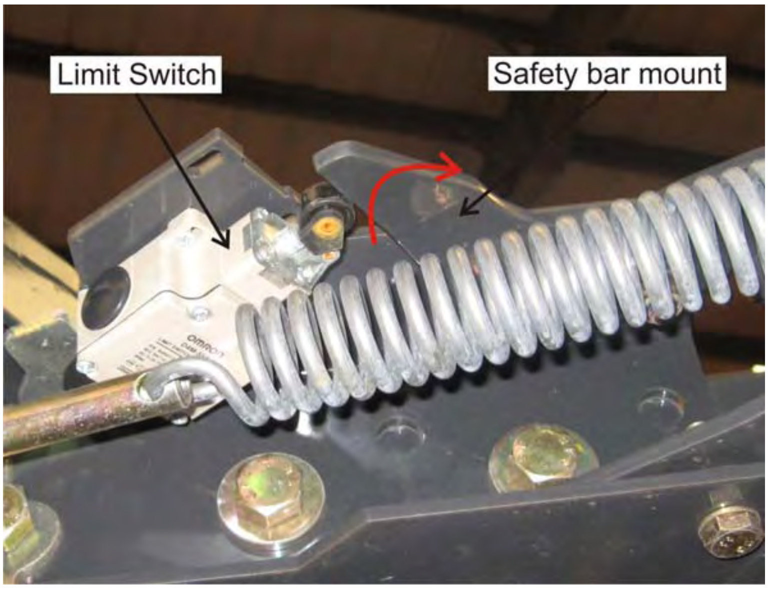

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Figure 8 Limit switch arrangement on Manufacturer B safety bar mechanisms

The initial linear gap between the leading edge of the safety bar and that of the dispenser arm was nominally 613mm on B1 and 620mm on B2. Therefore, as before, these are the distances within which it is desirable for the dispenser arms to have stopped rotating following initial activation of the safety bar in order that the dispenser arms did not pass this point of initial contact. These distances relate to a maximum arm rotation of 27^{o} on B1 and 26^{o} on B2 following activation of the safety bar before the leading edge of the dispenser arm will pass the point of initial contact of an object with the safety bar. The test results for Manufacturer B's wrappers are shown summarised in Table 3. Again during these tests the same hand held force gauge was used to measure the force required to activate the safety bars whilst the arms were stationary.

Table 3 Summary of results from testing of Manufacturer B bale wrappers

	B1	***B2***
Arm Diameter	2640mm	2740mm
Speed of rotation	35rpm	30rpm
Distance from safety bar to dispenser arm	613mm	620mm
Minimum stopping distance	825mm	1180mm
Maximum stopping distance	1110mm	1210mm
Mean stopping distance	996mm	1196mm
Required maximum angle of rotation to stop	27^{o}	26^{o}
Minimum angle of rotation to stop	36.4^{o}	51.0^{o}
Maximum angle of rotation to stop	49.7^{o}	52.4^{o}
Mean angle of rotation to stop	44.3^{o}	51.8^{o}
Mean safety bar activation force	102.1N	122.2N

Following the initial set of tests on B1 it was apparent that the arms were not stopping within the desired distance, and were overshooting the point of contact between the safety bar and trigger arm. The engineers then made various modifications to the wrapper set-up and further testing was carried out. It was found that by reducing the rotational speed of the wrapper to 29rpm from 35rpm, modifying the response of the electrical switch sensing the safety bar movement and modifying the back-pressure to the motor it was possible to reduce the stopping distance to around 450mm (20^{o} rotation), well within the desired 613mm.

4.3 MANUFACTURER C

Three bale wrappers were tested on the 8th April 2010. These three wrappers were designated as C1, C2 and C3.

On these wrappers there is an electric switch mounted on each of the two dispenser arms, these switches are positioned such that when a safety bar is activated, and moves back towards the dispenser arm, the switch is released. This breaks the in-series current supply to a hydraulic valve which controls the hydraulic fluid flow to the motor, this in turn leads to the fluid being diverted to by-pass the motor, and the motor stops. The drop in current supply to the valve coil is subsequently detected and the controller then completely shuts off the valve feeding the hydraulic fluid and a 'STOP' message is displayed on the controller screen. This requires re-setting before the arms can be re-started.

The initial linear gap between the leading edge of the safety bar and that of the dispenser arm varied between 810mm on C1, 750mm on C2 and 780mm on C3. Again, these are the distances within which it is desirable for the dispenser arms to have stopped rotating following activation of the safety bar in order that the dispenser arms did not pass this point of initial contact. These distances relate to a maximum arm rotation of between 25.8^{o} -27^{o} following activation of the safety bar before the leading edge of the dispenser arm will pass the point of initial contact of an object with the safety bar. The test results for these wrappers are shown summarised in Table 4. Again during these tests the hand held force gauge was also used to measure the force required to activate the safety bars whilst the arms were stationary.

Table 4 Summary of results from testing of Manufacturer C bale wrappers

	C1	***C2***	***C3***
Arm Diameter	3480mm	3360mm	3340mm
Speed of rotation	17.5rpm	25rpm	22rpm
Distance from safety bar to dispenser arm	810mm	750mm	780mm
Minimum stopping distance	810mm	536mm	630mm
Maximum stopping distance	830mm	686mm	740mm
Mean stopping distance	818mm	635mm	681mm
Required maximum angle of rotation to stop	26.9^{o}	25.8^{o}	27^{o}
Minimum angle of rotation to stop	26.9^{o}	18.4^{o}	21.7^{o}
Maximum angle of rotation to stop	27.6^{o}	23.6^{o}	25.6^{o}
Mean angle of rotation to stop	27.2^{o}	21.8^{o}	23.5^{o}
Mean safety bar activation force	102.5N	56.4N	59.4N

It can be seen that on two of Manufacturer C's wrappers that were tested that the dispenser arms stopped rotating well within the required distance for them not to pass the initial contact point of the test rig with the safety bar. However on one model, despite the slower speed of rotation, the stopping distance was approximately the same as the initial distance between the safety bar and dispenser arm, with some tests showing a slight overshoot (maximum of 20mm). In order to improve the stopping performance of the arms on this wrapper, the hydraulic oil pressure characteristics of the motor were modified such that the arms would stop rotating sooner. Doing this reduced the mean stopping distance to 657mm. During testing on C1 it was only possible to perform tests on one of the two safety bars as one of the safety bars was broken and in need of replacement.

4.4 MANUFACTURER D

A single combination baler/wrapper, was tested on the 21st April 2010. This machine was designated as D1.

The operation of the safety bar device on the Manufacturer D wrappers is similar to that encountered on the Manufacturer A wrappers, utilising the ‘flip-flop’ bar mounted centrally to the dispenser arm arrangement, beneath the motor hub. This ‘flip-flop’ bar holds an actuator in place whilst the cables attached to either end of the bar are tensioned (i.e. the safety bars are open and away from the dispenser arms as in normal running). Activation of either safety bar (moving towards the dispenser arm), de-tensions one of these wires, causing the flip-flop bar, and hence the actuator to drop. This shuts off the flow of hydraulic fluid that is driving the arm motor. Also, as the flip-flop bar and actuator drops, a sensor set on a target which also drops detects this movement and sends a signal to the main controller to depressurise the main line and stop the wrapping cycle which can’t be re-started by the operator until the safety bar is reset.

The initial linear gap between the leading edge of the safety bar and that of the dispenser arm, and hence the distance within which it is desirable for the dispenser arms to have stopped rotating following activation of the safety bar, was 435mm. This distance relates to a maximum arm rotation of between 17^o following activation of the safety bar before the leading edge of the dispenser arm will pass the point of initial contact of an object with the safety bar. The test results for D1 are shown summarised in Table 5. During these tests the hand held force gauge used to measure the force required to activate the safety bars whilst the arms were stationary was not available.

Table 5 Summary of results from testing of Manufacturer D bale wrapper

	D1
Arm Diameter	2490mm
Speed of rotation	33rpm
Distance from safety bar to dispenser arm	435mm
Minimum stopping distance	680mm
Maximum stopping distance	760mm
Mean stopping distance	723mm
Required maximum angle of rotation to stop	17.3^o
Minimum angle of rotation to stop	31.7^o
Maximum angle of rotation to stop	35.5^o
Mean angle of rotation to stop	33.8^o

It can be seen from these results that in this initial set of tests the dispenser arm over-shot the point of initial contact between the trigger arm and safety bar by between 245-325mm, this is illustrated in Figure 9 which shows the position in which the dispenser arms stopped after activation of the safety bar, with the trigger arm re-set to its starting point.

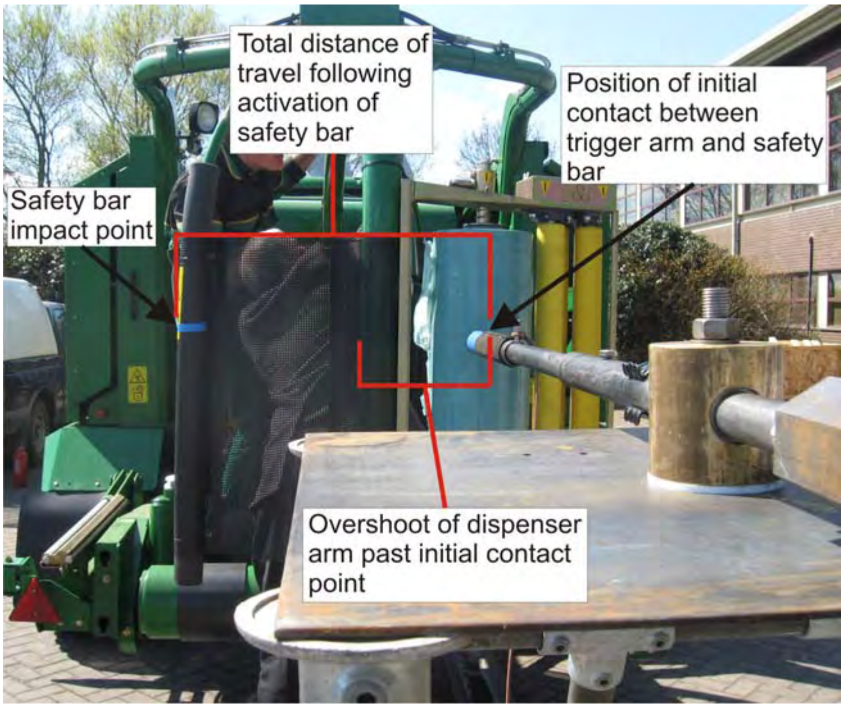

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Figure 9 Position of D1 following a test

As these initial tests showed a degree of overshoot, and indicated that the rotation of the dispenser arms was not stopping as quickly as desired the engineers made modifications to the wrapper and further tests were performed. It was found that by reducing the rotational speed of the wrapper to 22rpm the stopping distance was reduced to 380mm, well within the desired 435mm limit.

5 SPACING BETWEEN THE SAFETY BAR AND DISPENSER ARM

A further aspect of this work was to look into the spacing between the safety bar and dispenser arm. It follows that, as the space between the safety bar and dispenser arm increases, there is a greater distance/angle of rotation available in which to stop the arms rotating before the dispenser arm passes the point of contact between the safety bar and an object. However as this distance increases it introduces the possibility of an object or individual entering into the path of rotation in a position in-between the safety bar and dispenser arm, hence potentially being struck by the dispenser arm with no contact being made with the safety bar. This situation is further complicated by the speed of rotation of the arms. The faster the arms rotate, the larger the spacing between the safety bar and dispenser arm can be, assuming the time allowed to ingress into the intervening space is kept constant. This is also the case if the diameter of rotation is increased; this is because the effective linear speed of the dispenser arms increases with diameter (i.e. dispenser arms rotating at 20rpm will have an effective linear speed of 2.1m/s at a diameter of 2m but 3.1m/s at a diameter of 3m,) therefore in the same time period those dispenser arms which are held at a greater diameter, but rotating at the same rpm, will travel a greater distance.

Ergonomics Section, HSL assisted in gathering the data used for this section of the work. A number of assumptions had to be made with regards to the situations that the safety bar is intended to protect against, and the distances required for an individual to move to get into these situations. The most significant situation was taken to be the possibility of an individuals' upper body/head passing fully into the space between the safety bar and dispenser arm. The distance of movement required for this to happen, with the individual moving from an initial point of safety was taken to be 0.30m. The period of time taken for an individual to move this distance was found from data on average walking speeds (Reference 1). These average, normal walking speeds were 1.27m/s for women, and 1.46m/s for men. To provide a 'worst case' scenario a speed of 1.5m/s was used, giving a time to move 0.30m of 0.2s (200ms). Therefore the distance travelled by the dispenser arms in 0.2s was taken to be the maximum allowed spacing between the safety bar and dispenser arm. This gave the following formula for calculating the maximum spacing between the safety bar and dispenser arm:

$$x = 2r\left(Sin\frac{36s}{60} \right)$$

x = Spacing between safety bar and dispenser arm (m)
r = Radius of rotation (m)
s = Speed of rotation (rpm)

Some example spacings, calculated using this approach are shown in Table 6, and Table 7 shows the maximum recommended spacings for those machines tested during this work.

Table 6 Example safety bar to dispenser arm spacings

Diameter of arm rotation (m)	***Speed of rotation*** (rpm)	***Spacing from safety bar to dispenser arm*** (m)
2.00	20	0.42
	25	0.52
	30	0.62
	35	0.72
2.50	20	0.52
	25	0.65
	30	0.77
	35	0.90
3.00	20	0.62
	25	0.78
	30	0.93
	35	1.08
3.50	20	0.73
	25	0.91
	30	1.08
	35	1.25

Table 7 Example recommended spacings for machines tested

Machine	***Arm diameter*** (m)	***Speed of rotation*** (rpm)	***Actual spacing between safety bar and dispenser arm*** (m)	***Calculated maximum suggested spacing between safety bar and dispenser arm*** (m)
A1	2.66	31	0.42	0.85
A2	3.45	28.5	0.45	1.01
B1	2.64	35	0.61	0.95
B2	2.74	30	0.62	0.85
C1	3.36	25	0.75	0.87
C2	3.34	22	0.78	0.76
C3	3.48	17	0.81	0.62
D1	2.49	33	0.44	0.84

6 REFERENCES

1. Bohannon, R.W. (1997), Comfortable and maximum walking speeds of adults aged 20-79 years: Reference values and determinants

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Research into the effectiveness of safety bar devices fitted to satellite arm bale wrapping machines

This work identified a wide range of satellite arm bale wrappers available within the UK. Testing of these wrappers indicated that, as supplied, a large proportion of these wrappers have safety bar devices that do not perform in the manner desired. This is because in many cases, following the triggering of the safety bar, the rotating dispenser arms were not brought to an abrupt enough stop. This resulted in the dispenser arms passing the point at which the safety bar had been triggered, hence introducing the possibility of the dispenser arm striking whatever/whoever had triggered the safety bar. It is therefore apparent that bale wrapper manufacturers need to address this issue and develop solutions to improve the performance of the safety bar devices.

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