ICFR Bulletin 05/2013

A guide to safety requirements for excavator-based machines used in forestry operations

A project by the FESA Mechanised Harvesting Working Group (Mpumalanga)

P Schoombee, P Hall, C Inngs, BW Krieg, D Grobler, C Greyling, G Hogg and SA Ackerman

Produced by Forest Engineering Southern Africa (FESA)
and
The Institute for Commercial Forestry Research (ICFR)

Table of Contents

Key Findings

- Progressive identification of safety, ergonomic and economic guidelines for the conversion of non-purpose built machines for forestry harvesting.
- Converted machines primary and secondary harvesting/processing function need to be considered as they affect the required safety considerations.
- Identifies the minimum required for FOPS, ROPS, TOPS and OPS for converted machines
- Developed minimum standards for the maintenance of these modified components for non-purpose built machines.

A guide to safety requirements for excavator-based machines used in forestry operations

A project by the FESA Mechanised Harvesting Working Group (Mpumalanga)

P Schoombee, P Hall, C Inngs, BW Krieg,D Grobler, C Greyling, G Hogg and SA Ackerman

Institute for Commercial Forestry Research (ICFR), P O Box 100281, Scottsville, 3209, Pietermaritzburg, South Africa,
Telephone: +27 33 386 2314, Fax: +27 33 386 8905, www.icfr.ukzn.ac.za, e-mail: fesa@icfr.ukzn.ac.za

Summary

The increased cost of investing in purpose built forestry machines has led to adapting conventional industrial machinery for forestry purposes. With safety as the most important concern in all operations, there are no fixed standards relating to operator protection in these non-purpose built machines. This document serves to highlight possible dangers to the operator, and propose solutions best suited to the conditions and situations these machines operate in.

Keywords:

Chain shot

Excavator

FOPS

Harvesting

Hybrid machines

OPS

ROPS

TOPS

Introduction

Any employer in South Africa has a legal and ethical obligation to provide employees with a safe working environment in which to carry out their work. In forestry, mechanised harvesting operations generally lead to better operator protection than traditional motor-manual operations. They also lead to fewer people in the plantation, therefore further reducing the likelihood of someone being injured and can therefore be considered safer than motor-manual operations. Forest operation mechanisation, however, can introduce new hazards which do not exist in the motor-manual systems.

A typical equipment operator workplace (cab) is subjected to four main risks:

- The machine rolling over;
- The cab being hit by a falling object;
- Flying objects penetrating the cab towards the operator;
- The machine tipping over onto its side.

Almost any machine comes standard with roll-over protective structures (ROPS), falling object protective structures (FOPS), tip over protective structures (TOPS) and operator protection structures (OPS) applicable to the industry for which it was designed and built. When equipment from one industry (e.g. excavators from the mining and construction sectors) is introduced into another industry (e.g. forest harvesting), standard Original Equipment Manufacturer (OEM) machine specifications may no longer be sufficient to meet the new industry's safety requirements. Machines used in forest operations can include equipment from such sectors as mining and construction (e.g. excavators), agriculture (e.g. tractors) and forest equipment manufacturers (e.g. purpose-built machines). Most, if not all purpose-built forestry equipment is compliant with appropriate international forestry machine safety standards and therefore requires no modification.

The South African Occupational Health and Safety Act No. 85 of 1993 regards an excavator cab as an operator's workplace. It is therefore the employer's responsibility to fit any additional safety features and make any modifications as required to ensure a safe "workplace" for the employee, defined in the Act as "reasonably practicable".

Converted machines (hybrids) generally come at a lower capital investment than purpose-built machines, but are usually more limited in their capabilities. To reduce capital investment as well as for other reasons, converted excavators are used in forestry operations. The use of excavators may be an acceptable and/or recommended option for certain forestry operations under specific circumstances, given that risks associated with these machines are identified and risk control measures are implemented.

A standard for the protection of operators in excavator-based machines in a forestry application does not exist in South Africa. For this reason, this document provides guidelines based on international research and local expertise on the issue.

Guidelines for safety modifications to forest operation excavators

This report suggests appropriate guidelines to which excavator-based machines used in forestry operations should comply with regard to operator protective structures and machine limitations.

Lacking in most international standards and recommendations is the understanding that a "one size fits all" approach to excavator safety standards in forest operations may not be the best approach. A modified windscreen, for example, which can protect from chain shot (a piece of chain link snapping off and shooting off the cutting bar) may not be necessary or may require different specifications for a machine which does not have a bar and chain on the boom i.e. a debarking head, grapple and other such attachments. Another example could be the requirement of a reinforced cab top – this may be necessary if the machine is felling trees or loading logs, but possibly not if the machine only processes on roadside, at a safe distance from the felling and loading operations. It is therefore important to note that excavators in forestry operations can be used to perform different tasks.

Depending on the task the machine is required to perform (and the corresponding functional modifications/attachments the machine may use), the safety requirements for these machines may vary. Safety requirements are based on the function which the machine will perform in the plantation. **Table 1** outlines the safety requirements per machine type. This data assumes that machines will adhere to accepted safe working distances from other forestry machines during operations. It is also important to note that the data in the table specifies the minimum recommended guidelines for operator protection. A machine adhering to these guidelines may have more than the minimum suggested modifications, but should not have less. One should also note that if a machine is also a backup machine for a different operation, the safety requirements for that operation should be considered and complied with.

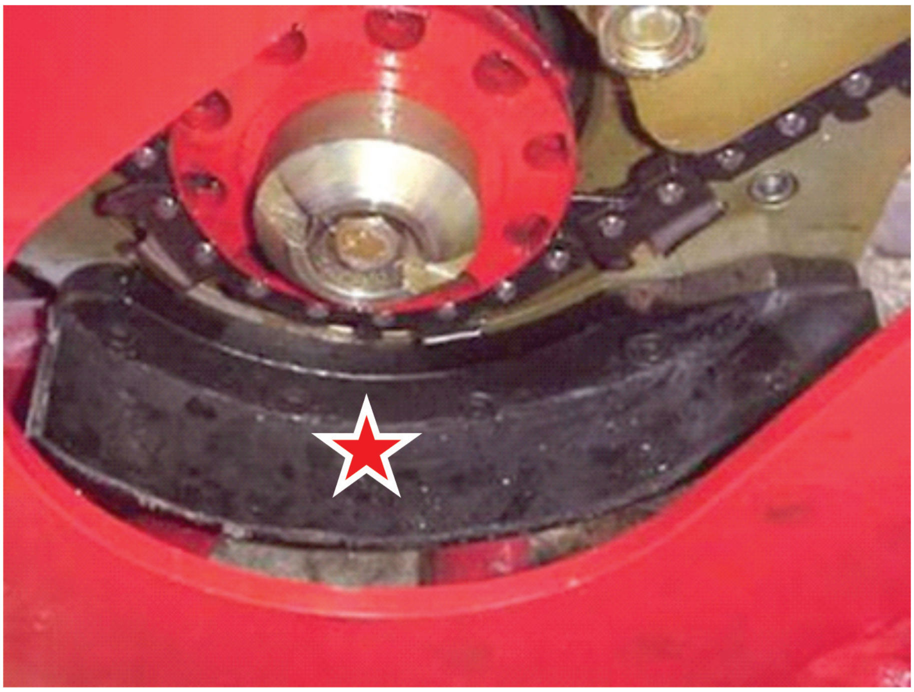


Figure 1. Chain shot guard (shown by the star on the picture) (adapted from New Zealand Department of Labour, 2005)

Table 1. Minimum safety requirements matrix for excavators in forestry operations.

Machine Type	Roll Over Protective Structures	Falling Object Protective Structures	Operator Protection Structures: Steel bars or steel mesh	Operator Protection Structures: Safety shield Polycarbonate glazing	Operator Protection Structures: Chain catcher and energy absorbing chain shot guard****	Tip Over Protective Structures (safety belts)
Harvester	Yes	Yes	Yes **	Yes ***	Yes	Yes
Felling machine	Yes	Yes	Yes **	Yes ***	Yes	Yes
Processor (roadside)	Yes	No	Yes **	Yes ***	Yes	Yes
Processor (infield)	Yes	Yes	Yes **	Yes ***	Yes	Yes
Debarker/Delimber (roadside) *	Yes	No	Yes **	No	No	Yes
Debarker/Delimber (infield) *	Yes	Yes	Yes **	No	No	Yes
Shovel Logging (roadside)	Yes	No	Yes **	No	No	Yes
Shovel Logging (infield)	Yes	Yes	Yes **	No	No	Yes
Log loading (roadside)	Yes	No	Yes **	No	N/A	Yes
Log loading (infield)	Yes	Yes	Yes **	No	N/A	Yes

(Essential Operator Protection Structures)

* A delimber/debarker machine is a machine that does not use a saw in any way, but delimbs and/or debarks felled trees. If the machine crosscuts and/or tops the trees which it is delimbing and/or debarking, it is classified as a processor and must then meet processor requirements.

** Steel bars or steel mesh: A machine may have either the bars or the mesh in certain cases (may not require both together). All machines require bars or mesh in front of the operator **unless a polycarbonate shield is installed which is thick enough to provide the same protection to the operator as the bars or mesh, and thus make the bars and mesh unnecessary**. When required, operator protective structures such as bars and mesh should be designed and installed to provide an adequate view for the operator to safely operate the machine.

*** International literature on chain shot tests with varying types of glazing material found that at least 19 mm laminated polycarbonate is needed to avoid chain link penetration (CMEIG, 2008). This thickness is recommended for these machines.

**** The chain catcher is a sturdy rod placed perpendicular to the centre of the drive sprocket. It can be mounted either to the drive shaft, or to the saw box, with a narrow gap to allow for chain installation and removal. A chain shot guard is an energy-absorbing piece of material (such as heavy rubber) mounted behind the drive sprocket (**Figure 1**). This guard performs two functions:

- Absorbs the energy of a broken chain coming into contact with the saw box, thus preventing chain parts from breaking off and being ejected; and
- Acts as an extension of the saw box, reducing the opportunity for thrown chain or chain parts to escape the saw box.

If damage has been sustained to any structure, the machine should be assessed by the OEM or its agent. If a protective structure has been damaged and its effectiveness compromised, the machine should be removed from the operation and the appropriate steps to repair or replace the structure should be taken. A machine may perform other work which does not require the damaged safety structure.

Standards from the International Organization for Standardisation (ISO)'s descriptions regarding safety standards for such equipment, along with other material, were used to determine the matrix in **Table 1**. The complete standards can be purchased from the ISO directly via their web site. The sections which follow, explain in more detail the requirements as outlined in **Table 1**.

Roll over protective structures (ROPS)

The ISO 8082:2003 standard establishes a consistent, reproducible means of evaluating the force-deflection characteristics of roll-over protective structures (ROPS) on self-propelled forestry machines under static loading, and prescribes performance requirements for a representative specimen under such loading. It is applicable to forwarders, skidders, feller-bunchers, processors, harvesters and loaders, as defined in ISO 6814. It is not applicable to machines having a rotating platform with a cab and boom on the platform i.e. an excavator. It is, however, useful in guiding the understanding of what an excavator needs to comply with when used in a forestry application.

Care should be taken to ensure the cab provides an appropriately safe environment to the operator, even during an accident. To this end, all work tools/utensils which belong in the cab should be securely fastened to prevent injury in the case of the machine rolling over (as a rule no loose objects which may injure the employee are allowed in the cab).

Falling object protective structures (FOPS)

The ISO 8083:1989 standard establishes a consistent, repeatable means of evaluating characteristics of protective structures under loading. This standard applies to mobile or self-propelled specially-designed machines as defined in ISO 6814. The standard requires that the protective canopy be constructed to protect the operator from injury due to falling trees, saplings and branches which might enter the cab side areas, and from broken winch lines or other objects. It also requires that the lower portion of the cab be fully enclosed with solid material, except at entrances. Additional roof protection may only be needed under certain circumstances (i.e. if the excavator is working close to standing trees and on the landing near high stacks). Excavators working away from the dangers of falling trees may not require roof protection.

Operator protection structures (OPS)

Recommendations for operator protection structures for this document were drawn up using, amongst others, the following three ISO standards:

1. The ISO 8084:2003 standard, which establishes a laboratory test method and performance requirements for operator protective structures (OPS) for self-propelled forestry machines. It is applicable to mobile forestry machines, defined in ISO 6814, engaged in felling, processing, forwarding and skidding. The OPS are designed to provide reasonable protection from objects being able to pierce, such as saplings, stumps, branches, broken winch lines and poking hazards in forestry work, but not from small, thrown objects such as chain links. Those OPS meeting the performance criteria will not provide complete operator protection under all conceivable circumstances, but are expected to minimise the possibility of operator injury in normal operational situations.
2. The ISO 11839:2010 standard, which specifies test procedures and performance requirements for determining the protective ability of panel materials used in forest machinery operator enclosures intended to protect the operator against saw teeth thrown by circular-saw components. This particular type of hazard is specifically defined by the size and velocity of the saw teeth and is unique to these cutting devices.
3. The ISO 11839:2010 standard, which is applicable to panel materials for forestry machines defined in ISO 6814 that include an integrated or attached circular sawing device, controlled or powered by the primary machine (e.g. topping saws, felling saws or bucking saws).

Protective bars and mesh

Bars and/or mesh are a necessity for all forestry operation excavator-based machines unless an appropriate polycarbonate shield is used to protect the operator. If the polycarbonate shield is not thick enough to adequately protect the operator, the excavator should have a cab that is fully enclosed with mesh material or vertical bars with openings no greater than 50 mm between the bars. The cab may be closed with other material where it can be demonstrated that such material provides equivalent protection and visibility. Visibility requirements are often not of a high priority for the lower portion of the cab where there are control panels or similar obstructions present.

Guards should be installed in front of all window areas exposed to flying or intruding hazards. These guards should be between a minimum of 100 mm and a maximum of 200 mm from the window surface. The guard should extend sufficiently beyond the sides of the window to prevent material from entering the cab from the sides. Guards should be designed to deflect potentially intruding objects (such as a tree length which is being debarked) away from the cab. These guards can be installed inside or outside the cab shield.

The enclosure structure of the upper portion of the cab should allow maximum visibility for the operator. Poor visibility will lead to unsafe working conditions, increased likelihood of accidents, accelerated operator fatigue and reduced productivity.

It should be kept in mind that neither bars nor mesh can protect an operator from foreign flying objects such as chain shot. For additional protection appropriate transparent shields or polycarbonate glazing is required.

Polycarbonate glazing as window protection

This transparent material is generally used to protect the operator from chain shot. It may also be used as a substitute for the bars and mesh described in the above section. When the polycarbonate is used as a substitute for bars or mesh, it should be laminated and the employer/manufacturer should demonstrate or guarantee that it provides equivalent or greater protection and visibility than the bars or mesh would have provided. Details on installation of polycarbonate glazing can be found in **Appendix 1**.

Although no detailed research was found on the shape of the protective shield, experience of the working group members has shown that a curved or angled safety shield may deflect flying objects away from the cab when hitting the shield. Safety shields which are mounted perpendicular to potential intruding objects are more likely to be penetrated by these objects, as the trajectory of the objects is not changed. The concept is similar to a car's windshield deflecting a stone away from the driver due to the windshield's shape. It is recommended therefore that the safety shield is not mounted perpendicular to any potential intruding objects.

Polycarbonate resistance to chemicals

The resistance of polycarbonate material to chemical exposure varies widely. The integrity of polycarbonate materials is not adversely affected by chemicals such as diesel, grease, hydraulic oil and engine oil. Other chemicals can seriously weaken the polycarbonate. While it is not possible to provide an exhaustive list of all chemicals which may damage the polycarbonate, one should take great care in allowing chemicals to come into contact with polycarbonate windows, and suppliers should be contacted to check for potential risk, before applying any chemical to the polycarbonate. Chemicals and compounds to avoid include petrol, acetone, benzene or solvents containing Butyl Cellosolve or Isopropanol.

Polycarbonate resistance to heated water exposure

Polycarbonate material has good integrity resistance to water (material does not degrade with exposure to water) up to a water temperature of approximately 65 °C. Above this temperature, the effect of water on the polycarbonate is related to the exposure of the polycarbonate over time. Exposing polycarbonate to repeated steam cleanings or high temperature pressure washing may result in crazing, a phenomenon that causes clouding of the surface.

Details on cleaning and maintenance of polycarbonate shields appear in **Appendix 1**.

Chain catcher and energy absorbing chain shot guard

Because of the high speeds, high stress, heavy loads, wear factors, and varying levels of repair and maintenance, there is a possibility that the chain or pieces of the chain or pieces of the disc can be thrown from the machine's head at high speed and with enormous energy.

This phenomenon is known as **"**chain shot**"** and involves the high-speed ejection of chain, or teeth parts from the machine attachment, and may occur in the event of a derailed or broken chain. Operators and bystanders are exposed to risk of serious injury in these situations. The Oregon's Mechanical Harvesting Handbook (2004) explains the phenomenon of chain shot in **Appendix 2**.

Chain shot is particularly dangerous in forestry operations because operators are inclined to use the chain when it is on the same plane as them (i.e. directly in line with them when working in front of the machine) to facilitate their view of the cutter bar when it cuts (an extremely dangerous method of working). If chain break occurs in this situation, projectile pieces can be flung from the saw box with the possibility that one of the chain links could travel directly towards the operator (**Figure 2**).

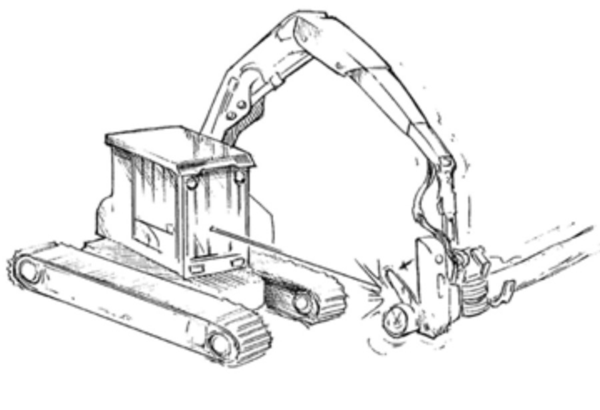


Figure 2. Chain shot: A link of chain snapping and being flung off the cutter bar (in this case, towards the machine operator) (WorksafeBC, 2004).

There are a wide variety of cutting tools with teeth that range in mass from a few grams to almost a kilogram used in forestry operations. There is also a wide range of operating speeds at which the cutting tools may work, depending on the type of cutter and the intended application. These objects can become detached from the machine attachment, at varying speeds. The general assumption is that thrown objects have an initial velocity equal to the tip speed of the cutting tool. No literature was found regarding the frequency of occurrence or incident rate of these pieces becoming dislodged from the head, but it is clear that preventative maintenance and good operator technique can reduce the likelihood of such an occurrence.

Machines need to be designed with appropriate guards and shields to minimise danger to operators and bystanders associated with chain break or disc projectiles. All operators should be protected by machine guarding and working position from such hazards. For maximum protection on machines using chains, chain catchers and energy absorbing chain shot guards should be installed.

Results of experiments done regarding chain shot appear in **Appendix 3** and serve as further information for the reader. Following this, detailed information on safety measures are also listed in **Appendix 4**.

Tip over protective structures (TOPS)

ISO 8082-2:2011 code refers to TOPS relevant to excavator type of equipment.

Excavators generally do comply with most TOPS requirements as necessary for forestry operations. An important aspect of TOPS is the seatbelt in the machine. The following considerations should be adhered to regarding seatbelts:

- Operators should use the available seatbelt while the vehicle or machine is being operated.
- Seatbelts should not be removed from any vehicle or machine.
- Seatbelts should be maintained in a serviceable condition.
- Either adjustable lap belts or inertia belts are acceptable.
- As an exception, a training instructor will be exempt from wearing a seatbelt.

All doors should also be closed and securely fastened during operations.

Operator protective structures and guarding should still allow for a minimum of two exits, thus ensuring that if the machine tips over and blocks a door, the operator can still exit the machine. The alternative emergency exit should be clearly marked both inside and outside the cab and should adhere to the following:

- It should not be located on the same surface as the cab entrance door.
- It should be usable regardless of the position of moveable components or accessories of the machine.

- It should not pose additional hazards to the operator.
- It should be designed so that it can be opened from the inside and the outside without the use of additional tools, except tools provided with the machine to be used on the emergency exit.
- Opening the exit should require a force of not more than 147 kilogram-force/square metre.
- It should provide a clear opening for the operator to exit of at least 65 cm in diameter if circular, 60 cm on each side if square, and 47 cm by 65 cm if rectangular.

Conclusions

This document is intended to be used as a guideline to the safeguarding of operators of excavator-based forestry operation machines. It is the responsibility of the employer, however, to ensure that employees are adequately protected and safe in their workplaces. It is recommended that a risk assessment be undertaken when purchasing new equipment to consider if additional engineering designs are required. Ultimately, the selection of a machine and the modifications which need to be made depend on the primary work for which the machine will be used, the secondary work for which it will be used, the operational environment and economic considerations. It is the responsibility of those who select the machine to determine the relevant information to be provided to a supplier so that both parties can make a well-informed decision on machine suitability and associated safety risks.

Sufficient ROPS, FOPS, OPS and TOPS should be installed using a suitably qualified and competent institution. One must also clearly define operational capabilities on the machine, for example slope limitations. Operators must be trained and competent in the use of the machine for its intended use and its limitations. The machine and its components also need to be maintained to an acceptable standard. It is the responsibility of the employer and the employee to ensure that the machine is used within the operational parameters, and/or site specific restricted operational parameters.

References

CMEIG. 2008. Chain Shot Phenomenon. Engineering Position Paper No.4 – Amended 18 September 2008. Construction and Mining Equipment Industry Group Inc. [Online]. Available at: http://www.cmeig.com.au/documents/CMEIGPositionPaper-ChainShotPhenomenon.pdf. [2012, October 24]

New Zealand Department of Labour. 2005. Operator Protection Against Chain Shot. *Forestry Bulletin* No. 134. September 2005

Oregon. 2004. Mechanical Timber Harvesting Handbook. [Online]. Available at: http://www.oregonproducts.com/pdf/harvester/MechanicalHarvesting_2005.pdf. [2012, October 24]

Rummer B, Klepac J. 2011. Thrown Object Hazards in Forest Operations. 2011 National Symposium on Agriculture, Forestry and Fishing Health and Safety – Paper No. 11-05. [2012, October 24]

Rummer B, Taylor S, Veal M. 2012. New Developments in Operator Protection for Forest Machines. [Online]. Available at: http://www.srs.fs.usda.gov/forestops/presentations/NewOPS.pdf

WorkSafeBC. 2004. Incident bulletin NOA 596: Broken chain drive link penetrates protective window, striking feller processor operator. [Online]. http://www2.worksafebc.com/i/posters/2004/ib_processor.htm. [2012, October 24]

Useful literature and links

Barker R. Focus on Safety – Care of Polycarbonate Windows in Tigercat Operator's Stations. [Online]. Available at: http://www.tigercat.com/images/stories/safety/care_of_polycarbonate.pdf. [2012, October 24]

BC Forestry Safety Council. 2011. Safety Alert of the Month – How Chain Shot Happens. [Online]. Available at: http://www.bcforestsafe.org/AOM_January_2011. [2012, October 24]

Forest Safety Code (Tasmania). [Online]. 2007. Available at: http://www.wst.tas.gov.au/__data/assets/pdf_file/0009/81873/COP006.pdf. [2012, October 24]

PAR Group LTD. Technical Specifications – Makrolon Polycarbonate Sheet. [Online]. Available at: http://www.par-group.co.uk/engineering-plastics/makrolon_polycarbonate_sheet.aspx. [2012, October 24]

SABIC Innovative Plastics. 2009. Lexan Sheet - Processing Guide: Forming, Fabricating, Finishing and Decorating Solid un-coated and coated sheet. Technical Manual

United States Department of Labour – Occupational Safety and Health Administration. Logging operations Regulation 1910.266. [Online]. Available at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9862. [2012, October 24]

Workplace Standards Tasmania. 2005. Safety Alert: Chain Shot – A High Level of Risk to Forest Workers. Bulletin No. 1 of 2005

WorkSafe Victoria. 2007. Safety in Forestry Operations: Harvesting and Haulage. [Online]. Available at: http://www.worksafe.vic.gov.au/__data/assets/pdf_file/0009/10224/WorkSafeForestryGuide.pdf. [2012, October 24]

WorkSafeBC Publication. 2005. Protective structures for hydraulic excavators pioneering on steep side hills. Part 16: Mobile Equipment. [Online]. Available at: http://www2.worksafebc.com/publications/ohsregulation/guidelinepart16.asp.
[2012, October 24]

Appendix 1: Polycarbonate glazing: Installation, inspection, maintenance and cleaning instructions.

Installation

The following details should be taken into account:

- Drilling into the shield is not allowed.
- Check compatibility of the shield with the suppliers of the selected glazing tapes, gaskets and sealants.
- Thermal Expansion Allowance: Care should be taken to allow free expansion of the sheet to avoid bowing and thermal stress. Product suppliers should be consulted for Linear Thermal Expansion Coefficients. Allowance for thermal expansion should be made for both the length and the width of the shield.
- When using glazing compounds, it is essential that the sealant system can accommodate a certain amount of movement to allow for thermal expansion, without loss of adhesion to the frame or sheet. Momentive Performance Materials (MPM) sealants are generally recommended for use. It is strongly advised that when using a sealant other than Momentive Performance Materials sealants, its compatibility be checked before use.
- All shields should be marked to show thickness and grade of the material.
- The shield, if fitted in addition to the existing shield, should be fitted on the outside of the existing shield in a separate frame, not mounted on the machine cab, if possible.
- Sufficient space should be allowed between the cab frame/shield and shield frame to accommodate cleaning of both glass and shield surfaces.
- International literature on chain shot tests with varying types of glazing material found that at least 19 mm laminated polycarbonate is needed to avoid chain link penetration in most cases (CMEIG, 2008). A thickness of 19 mm is recommended.

Inspection and maintenance

Daily inspection and maintenance of the shield is essential to ensure that its protective ability has not been compromised. The following points detail some of the inspection and maintenance matters to be considered:

- Inspection of all windows should take place daily and immediately after any impacts.
- Any damage to the window material or steel structure in the area of the window mounting should be assessed.
- The edges of the shield should be free from cracks or chips and should not be pinched or stressed. Shields with these defects should be replaced immediately before work is allowed to continue.
- Cracks, chips, breaks or scars anywhere on the shield's surface will decrease its impact strength. Shields with these defects should be replaced immediately before work is allowed to continue.
- Bent, dented or missing shields retaining parts should be replaced immediately before work is allowed to continue.
- Rubber materials used in mounting the shield should be maintained in good condition.

Concealing hairline scratches

The appearance of scratches and minor abrasions on the surfaces of polycarbonate windows can be glossed over using a mild automotive polish such as Johnson's Paste Wax, Novus Plastic Polish #1 and #2 or Mirror Glaze Plastic Polish. The polycarbonate window should be cleaned as outlined below prior to the application of an automotive polish.

Cleaning

Safety shield should be kept clean to ensure operator visibility. The following should be adhered to when cleaning the polycarbonate:

- Do not use petrol, acetone, benzene, or solvents containing Butyl Cellosolve or Isopropanol.
- Never use strong alkali or abrasive cleaners.
- Never steam clean.
- Do not use brushes, razor blades, scrapers, squeegees or other sharp tools.
- Do not use abusive cleaning procedures either by hand or pressure washing on polycarbonate windows.
- Don't clean shield in the hot sun or at elevated temperatures as this can lead to staining.

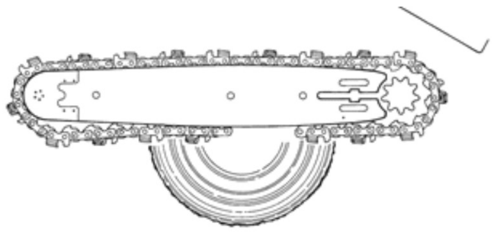
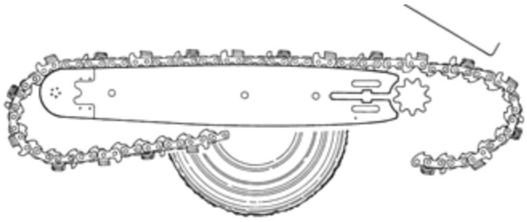
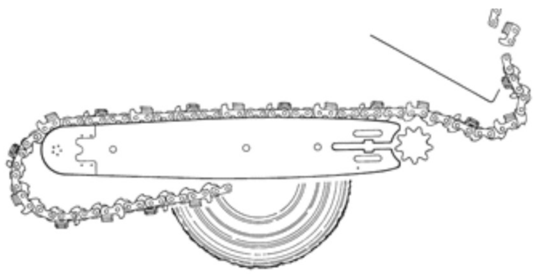
The following step-by-step procedure should be followed for cleaning the polycarbonate:

1. Rinse the window thoroughly with lukewarm water.
2. Using a soft cloth, cellulose sponge or chamois, gently wash the window with a mild solution of soap or detergent in lukewarm water. Do not scrub or use brushes or squeegees. Polycarbonate manufacturers should be consulted as to the cleaning agents which should be used on the polycarbonate.
3. Rinse the window thoroughly with lukewarm water.
4. Dry the window with a moist soft cloth, cellulose sponge or chamois to prevent water spotting.

To remove grease or oil from the polycarbonate, first rub lightly with a good grade of VM&P Naphtha or isopropyl alcohol followed by the same rinse, wash, rinse and dry procedure described in steps 1 to 4 above.

Failure to follow the cleaning instructions outlined in this section will shorten the service life of the polycarbonate and may cause visual hazing, loss of light transmission and delamination of the polycarbonate hard surface coating.

Appendix 2: Sequence of events relating to the chain shot phenomenon

Sequence of events	Diagrammatic representation
After a chain break …………	
The free end of the chain begins to whip away from the break.	
If the chain is not contained by the saw box or an energy-absorbing guard, the broken chain's free end can speed up rapidly and carry immense dynamic energy.	
At the peak of the whip, chain parts may break loose and be ejected at high speed, especially if the free end of the chain strikes the saw box. Chain shot can cause chain parts to be thrown in many directions, especially along the plane of the saw bar.	Fragments have been measured at between 180 and 310 m/s under laboratory simulated conditions.

(Oregon, 2004)

Appendix 3: Chain shot research results

Results from two research studies are presented in **Table 2**, which demonstrate the impact of chain shot in a forestry environment. The first are results of a study carried out by B Rummer from the USDA Forest Service and Taylor and Veal from Auburn University (Rummer *et al*., 2012). Two types of polycarbonate shields were tested for their ability to stop chain shot from penetration; 13 mm mono shield and 19 mm 3-ply shield. A chain link was used in the tests at varying velocities (and thus varying energies). Results presented in **Table 2** for the two shields, indicate whether they passed (i.e. the chain link did not pass through them) or failed (i.e. the chain link did pass through them) at the varying velocities.

Table 2. Research results of the impact of chain shot from studies conducted by Rummer *et al*., (2012).

Polycarbonate Shield Thickness	Projectile	Pass	Fail
13 mm mono	Velocity (m/s)	83	87
	Energy projected (kJ)	6.8	7.5
	Energy absorbed (kJ)	6.4	6.3
19 mm 3-ply	Velocity (m/s)	105	113
	Energy projected (kJ)	11.0	13.0
	Energy absorbed (kJ)	10.5	12.5

A mono polycarbonate shield of 13 mm is insufficient to withstand a chain shot velocity of 87 m/s and laminated 19 mm Lexan is insufficient to withstand a chain shot velocity of 113 m/s. Chain shot tests on different types of glazing material found that at least 19 mm laminated polycarbonate is needed to avoid chain link penetration (CMEIG, 2008).

Data in **Table 3** summarises typical mass, velocity and energy figures with comparative ballistic benchmarks (Rummer and Klepac, 2011) suggesting that chain shot has properties similar to those of a 9 mm bullet. Saw teeth and mulcher teeth, while in some cases comparable in energy to a shotgun slug, are heavier and slower.

Table 3. Comparison of similar energy values (Rummer and Klepac, 2011).

Type of object	Mass (g)	Velocity (m/s)	Energy (J)
.404 chainsaw tooth	11	300	495
50 mm saw tooth	300	85	1084
60 mm saw tooth	800	110	4840
Fixed tooth mulcher	1800	46	1904
9 mm bullet *	8	358	513
12-gauge rifled slug **	28	483	3266

* Level 1 ballistic criteria from UL 752 (UL 2000)

** Supplementary Shotgun ballistic criteria from UL 752 (UL 2000)

The second study is research carried out on chain shot by the CMEIG in 2008. Three polycarbonate shield configurations were tested in the study in terms of their chain link projectile arresting properties and the results are presented in **Table 4**.

Table 4. Polycarbonate shield test information and test results (CMEIG, 2008).

Type	Thickness (mm)	No. of tests	Observations	Description
1	19	10	Projectiles were able to penetrate the material and cause a 5 mm deformation on the rear surface on the window.	Polycarbonate - LEXGARD® RC-750 laminate - 3-ply LEXAN® polycarbonate
2	19	7	Projectiles where able to penetrate the outer polycarbonate layer, but were contained by the acrylic layer. The rear layer of polycarbonate was not penetrated, however it was partially delaminated.	Polycarbonate / Acrylic - LEXGARD MP750 laminate is a 3-ply LEXAN® polycarbonate and acrylic laminate
3	32	9	Projectiles were able to penetrate the material to a maximum depth of 18 mm.	Polycarbonate - LEXGARD® SP-1250 laminate - 4-ply LEXAN® polycarbonate laminate

All of the polycarbonate shields tested in the study arrested the chain link projectiles fired at them. However, it is evident that the thicker shield provides a safer work environment for the operator.

Appendix 4: Safety measures to reduce the likelihood of chain shot and injuries

The following safety considerations should be incorporated into operations to reduce the likelihood of chain shot as well as related injury should chain shot occur:

- Maintain the saw chain in a good condition.
- Use pre-assembled chain loops.
- Frequently inspect the chain and bar, especially after any unusual incident.
- Remove and inspect the cutting equipment at least daily for excessive wear damage. Check particularly for cracked chain parts. Remove damaged or cracked chain from service.
- An efficient form of communication should be in place between all operators working within the mechanised system.
- The use of sirens or radios or some other communication method to inform all operators to cease work immediately should be considered.
- Ensure all parts of the cutting equipment are properly aligned.
- Maintain the saw chain, including depth regulators, to the manufacturer recommendations.
- Never use the saw so that the saw bar is directly in line with the cab or other persons.
- Ensure chain speed does not exceed the chain manufacturer's rating. Control the chain's speed to below 35 m/s for ¾-pitch chain or 40 m/s for 0.404-pitch chain.
- Ensure operators and bystanders stay clear of the plane of the saw bar when operational.
- Install a chain shot guard near the drive sprocket.
- Remove dull chain from service.
- Maintain proper bar and chain lubrication and chain tension.
- Replace the drive sprocket when visibly worn.
- Keep ground workers at least 70 metres (230 feet) away from a working harvester/processor.
- Do not re-use bent or damaged chain links or riveted connecting components when making repairs to chains.
- Follow recommended practices for maintenance and use of the chain, bar and sprocket.

Further reading on chain shot, operator training, instructions, machine manuals, decals for harvester heads and other related subjects can be found at the locations listed below, as well as the references listed on the last page of this document:

- Oregon® Mechanical Timber Harvesting Handbook http://www.oregonchain.com/harvester/pdf/MechanicalHarvesting_2005.pdf_
- Chain shot warning in four languages__http://www.oregonchain.com/harvester/pdf/HarvesterChainShotWarning.pdf_
- Chain shot warning label_http://www.oregonchain.com/harvester/pdf/ChainShotWarningLabel.pdf_
- Chain shot decals_ http://www.oregonchain.com/harvester/pdf/ChainShotSymbol_4Color.pdf_
- Chain shot computer simulation_http://www.oregonchain.com/Harvester/service/ChainShotSimulation.avi_
- Workmen's Compensation Board of British Columbia, Canada_http://www.healthandsafetycentre.org/media/fss/harvester/slideshow.htm