Understanding the Hazards of Thrown Objects: Incidents, Research and Resolutions

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Abstract: Improved rotating cutting devices (teeth on a disk/drum or cutters on a chain) for forest operations have produced hazards for operators and others from thrown objects. Anecdotes and actual incidents show fatalities and serious injuries are possible and likely under certain circumstances. Some mechanisms for thrown objects are clear (thrown cutting teeth) while others are less obvious and need explanation (chain shot, thrown spears and stubs). Research on thrown objects and protective materials provides insights on the problems. Resolutions to the problems come from improved guarding, protecting operators and others, and changing operating practices. The effectiveness of a specific no-entry force field around the machine is questioned. Safety standards at the state, national, and international levels address the issues. Authors discuss implications for anyone working in the vicinity of cutting machines.

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Introduction

Rotating cutting devices used in woods work have improved the efficiency of forest operations immensely since their development. Chains on saws can travel 15,000 revolutions per minute (rpm) and heavy disks or drums over 1,700 rpm. The rotational energy coupled with cutting edges provides tools for cutting trees; masticating, chipping or grinding vegetation and debris; and even chewing up forest road surfaces. But what happens when the rotational energy is converted to translational energy in the form of thrown objects? What hazards are faced by operators and other workers? What are the actual mechanisms that throw objects? What does research tell us about the phenomenon? What can be done to protect people from these hazards? What are the implications for anyone working around cutting machines? These questions need assessment and response.

Incidents and Anecdotes

Forestry folks know there are hazards from thrown objects from some of the anecdotes circulating in the industry. There is the story about a saw tooth from a disc saw being retrieved from halfway through a skidder's engine block. How about the logging contractor walking the unit toward his operation and seeing something moving along the ground and hitting his steel-toed boot? He picked it up and recognized it as a saw tooth from his disk saw—an operation nearly a half mile away. There is an oak firewood section in a Texas saw shop that is split down the middle showing a disk saw tooth imbedded at least 10 inches into it (author observation).

There are also documented incidents that resulted in fatalities or injuries. Some are documented in the lawsuits where one of the authors served as an expert. For example, a Mississippi timber cutter walking to his vehicle past the landing where a wheeled feller-buncher was clearing hardwood saplings was struck by a blunt spear thrown from 40-50 feet away. The object did not penetrate the cutter but did internal injuries resulting in his death at the landing. In another case, a landing sawyer was limbing and topping a tree when he was knocked to the ground. He reached to his back and pulled out a four foot long, ~three inch diameter stick. He survived but lost his spleen and suffered other internal injuries. The stick had distinctive saw marks at the same spacing as the teeth on the disk saw that threw the object from ninety four feet (94') away. Similarly, a Texas sawyer was limbing and topping near the landing when he was struck in the head by an eight inch (8") long, five inch (5") diameter sweetgum stub from over three hundred thirteen feet (313') away from where the feller buncher was working. Other similar stubs were found some distance from where the sweetgums were growing. The sawyer was wearing a hard hat.

The Workers Compensation Board of British Columbia documented severe injuries to a harvester operator struck by a chain link (chain shot) that passed through a half inch (1/2") polycarbonate cab window. In another legal matter, a worker was struck in the abdomen by a chain link (chain shot) from a manual chainsaw operated about thirty five feet (35') away. Another worker was cutting a dead stump of a tree broken off by wind (~10-12' tall) when his chain broke. The section of broken chain flew through the air and impacted the nearby worker. The chain piece removed in life-saving surgery caused injuries similar to being shot by a bullet. A different incident caused injuries to a bystander at a demonstration of a forestry mulcher when a six foot (~5-6'), four inch (4") slab shot out from beneath the machine. The slab traveled just above the ground and then went vertical before striking the bystander standing with his colleagues eighty-five feet (85') away. While he survived, damage from the object was made worse by infections received during hospital treatment (MRSA). Other anecdotes and incidents demonstrate the hazards of thrown objects.

Mechanisms of Thrown Objects

Circular Cutting disks and drums can throw teeth that break or come loose along a tangent line from the circle at the point of release. There is little published information about the actual failure modes of disk saw teeth. Anecdotal reports suggest that loosening of mounting bolts may lead to detachment. Teeth may also fracture on impact with rocks or other debris. Operators report missing teeth or noting excessive vibration while cutting. In general, the assumption is that if a mounting bolt fails, the tooth would separate from the holder and be carried in the debris stream around the inside of the saw shroud. At the discharge point the tooth could be moving at the tip speed velocity. The rotational velocity in revolutions per minute (RPM) varies by machine type but many use the stored inertial energy of heavy rotating drums or disks operating from 1000 to about 1500 RPM. The rotating velocity may drop to half its original (or much more) during the cutting cycle and then recover as mechanical energy is added to bring the RPM up to a pre-set level. Typically operators stop the inertial rotating cutters by "grounding" the cutter in a stump or into the ground.

A survey of high-speed sawhead specifications identified over 40 models in current production. Older designs are still in use, but specifications were unavailable. Most of the designs (68%) rotated at 1300 RPM or greater, although the speeds ranged from 600 to 1650 RPM. Combining rotation with disk diameter reveals a narrower distribution with almost all designs (88%) working at a tip velocity that exceeds 85 m/s (~254 ft/s). The highest tip speed was 102 m/s (~316 ft/s). These survey data (Fig. 1) provide an indication of design trends, but are not comprehensive or weighted by numbers in service.

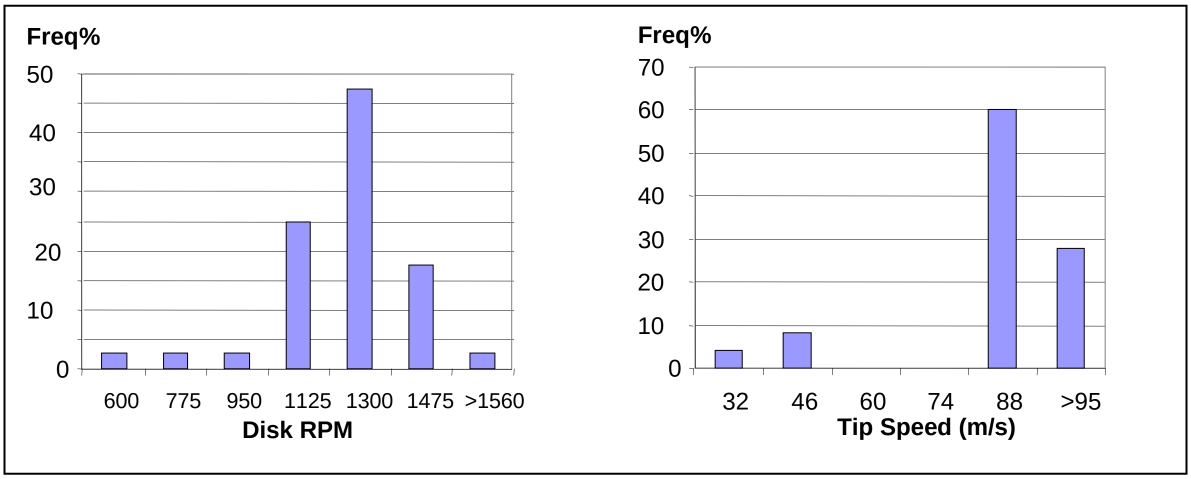

Figure 1. Comparison of high-speed sawhead designs.

Ballistic equations from high school physics provide a first look at how far rotating cutters can throw compact objects like saw teeth. Recall that the range (X) of a projectile does not depend on its mass and follows the equation:

$X_{max} = v^2 \sin(2\,\theta) / g$ where v=velocity, θ= flight angle from horizontal, g=gravitational constant (est. 32.2 ft/sec^2)

Thus, a tooth from a disk saw about two and a quarter pounds (2.25) leaving a fifty-five inch diameter disk (55") rotating at thirteen hundred (1300) RPM at an angle of forty-five (45) degrees might travel over three thousand feet (~3023').

<u>Spear-like objects</u> thrown from rotating cutting heads are more difficult to describe. Their flight trajectories take on aerodynamic characteristics making them unpredictable once they leave the machine. Initially, some rejected the idea that disk saws could throw spears. However, home woodworkers may have experienced a similar phenomenon when their tablesaw catches a scrap that comes against the rotating teeth and is thrown violently. One of the authors duplicated the mechanism by throwing three foot (3') long and one inch diameter (1") dowels into hay bales. The mechanism involves one tooth just catching (but not cutting) the spear and each successive tooth adding similar translational energy for a few teeth until the spear moves away. The energy transferred by this

mechanism was impressive in that the dowels would be driven fourteen (14") inches into the hay bale. Once understood, the throwing mechanism could be predictably replicated. One manufacturer was unsuccessful at throwing 2x4's full scale with a disk saw on an excavator until a fellow added some liquid soap that mimicked sap and moisture to overcome friction. The reduced friction was more like woods conditions and they were able to throw 2x4's over two hundred (~214') feet across the gravel pit.

Stubs (small chunks of saplings/hardwoods) can be thrown some distance (>300') and injure unprotected workers. The throwing mechanism is apparently a vertical version of when a tablesaw nearly cuts off a segment and then barely touches the small cut section with the saw teeth. The small section is not cut but rather broken away and thrown violently in the direction the saw is turning. The documented Texas case of a thrown stub described earlier came from the practice of first clearing away saplings or hardwoods at about a foot off the ground. The machine could then access the larger trees for cutting nearer ground level. However, when the disk saw would return and pass through the cut stubs, several teeth would nearly cut off the stub while the following teeth would strike the stub, break it away, and throw it in the tangential direction from the saw. Examination of the stubs distant from where they were grown showed a small strap of wood/bark still attached. Attempts to simulate the thrown stubs by tossing samples against a turning disk saw were not successful. Some operators acknowledge the thrown stubs but cannot see what causes them.

Chain shot is the term used to describe when a piece of a saw chain is thrown into the operating area creating a hazard to workers. Manufacturers demonstrated chain shot by intentionally weakening chain and using high speed photography to see what happened. Not all broken chain ends up with a chain shot. When the loose end of the chain comes free and cracks like a whip, chain shot can often be seen in the high speed photos. There may be other conditions that produce chain shot--like the chain hitting something but they have not been replicated. Chain shot can occur both on chainsaws and cutting bars using chains on mechanized equipment. The first step is for the chain to break and a number of causes produce a break:

- Improper tension—chain too loose
- Improper chain maintenance or repair (hammered rivets)
- Damaged sprocket, bar and/or chain
- Improper bar and chain lubrication
- Defective chain
- Excessive chain speed—new chainsaws can drive chains faster than their design and harvesters can be adjusted to push chain to excessive speeds

Swedish researchers have estimated that a chain shot might occur within the frequency of about once every fifty (50) chains replaced during operations (Hallonborg 2002).

Research

Testing conducted by the US Forest Service examined how properties of polycarbonate glazing panels may affect the ability to resist penetration by saw teeth (Veal et al. 2003). Projectile size, type, impact angle, and velocity were varied. Alternative polycarbonate panels were tested to examine effects of panel size, thickness, construction, curvature, and temperature. The principle findings were that 0.5" monolithic polycarbonate was not sufficient to stop penetration of large sawteeth at high velocity. It was also determined that curved windows and larger openings were not more likely to fail than smaller openings. Panel temperature, however, was the most significant factor affecting performance of polycarbonate. All tests of monolithic material below 0°F resulted in brittle failure. This testing program serves as the basis for the development of new equipment standards described below.

Resolution and Results

Not surprisingly, when incidents occur and legal issues arise, there are responses to the perceived problem. Manufacturers, safety agencies, operators and others try various approaches to reduce the hazards of thrown objects. Safety professionals recognize the abbreviated hierarchy of hazard mitigation:

- Design/engineering modifications to eliminate the hazard
- Operating modifications to avoid human exposure
- Personal/machine protection with safety apparatus (clothing, protective structures, etc.)
- Warnings, labels, training, and signage

Industry responses include the approaches below.

<u>Guarding of Circular Disk Saws</u>—For some inertial saw types, the saw felling disk extends forward beyond the side guards or is about even with them. These saws present the most opportunities to throw objects. Additional length of the saw guards can minimize the chance for spear like objects to be thrown. In reality, only the guard on the side of the direction of disk rotation need be of sufficient length (right side facing a clockwise rotating disk). The length of the guard can be estimated by the tangential line from the disk extending past the guard. Using a reference of a clock face with 12 o'clock designated the direction of the straightforward line of the saw, only the tangential lines from about 10:00 to about 12:00 o'clock provide the need for guarding. Practically, to reduce the hazard of thrown spears, the length of the guard in the direction of disk rotation need only extend to a point where the tangential line from a likely thrown object would not strike the guard. The geometry of curves, middle ordinates, and deflection angles (δ) for such a guard where the cutting opening for the disk saw is half its diameter (the radius r) yields a guard of a length **G** beyond the leading edge of the saw as
$\mathbf{G}= r/\sqrt{3}-r+(\sqrt{3}/2)r$ Where the saw diameter is a 2r=55 inch disk, then the guard length is **G**=~12 inches (12.19'')

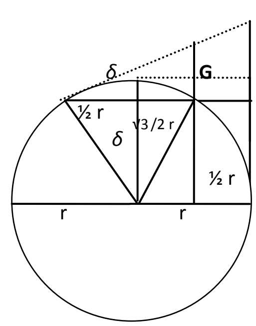

Figure 2. Geometry of disk saw and thrown objects.

Some disk saws have guards meeting this rough criteria while others fall short providing various hazards.

Guarding Rotating Drums – Cutting/mulching drums typically rotate forward in the direction of machine travel. Objects may be thrown forward as the cutting teeth strike the object or ejected from the bottom of the drum under the machine. Traveling forward the strike point of the rotating drum is most likely from the horizontal plane to the ground level, and pusher bars and head controls facilitate this geometry. Some machines lack any barriers to thrown objects ejected beneath the machine. Others use vertical chain links or strips of conveyor belting to impede the discharge of thrown objects. A hanging “bang plate” has also been suggested as a stopping barrier but is not evident on machines seen by the authors. Whatever barrier is used, it must extend to the ground level of the machine as the spears thrown by cutting heads may be less than 2 inches (2”) in depth. The design of such barriers under the machine is beyond the scope of this paper but testing of such designs seems in order.

Improved Chains, Maintenance, Control of Chain Speed and Chain Catchers may reduce hazards of chain shot. Some saw chain may not be designed for the speed of the current saws and improperly maintained chain will have a point of weakness. The first step is to keep the chain from breaking. Some harvester operators have been known to increase the cutting speed beyond manufacturers’ recommendations for their cutting heads. Chain manufacturers have adapted chains for higher speeds, harvester heads, and difficult operating circumstances. It is unclear whether the chain speed needed to eliminate chain shot would render the saw cutting features useless. In addition, some chain saws and harvester heads have “chain catchers” which may reduce the whip like action that produces chain shot. This is the approach proposed in the committee draft International Standard 11837.

Operating Modifications to reduce human exposure provide some immediate hazard reduction. For example, earlier training instructions often directed harvester operators to cross cut the stems immediately in front of them to see that cuts were made properly. Current guidelines call for avoiding the chance of chain shot directly at the operator by repositioning the stems for crosscutting where a chance breakage would not be in line with the operator. Operating modifications for disk felling heads have some practical problems. It may be possible to separate workers on the ground from cutting operations using space and timing of operations, especially when cutting saplings/hardwoods near the landing. However, other machines that operate nearer cutting operations and operations in the urban fringe put cutting heads proximate to people. Workers on the ground approaching a disk saw can recognize the direction of rotation and approach such machines from the opposite side. Discharge from cutting/mulching drums is typically rearward, leaving the machine approachable from the sides. However, such machines move and turn quickly in relation to the work ahead of them.

Personal/machine protection from thrown objects is under consideration. Workers on the ground probably cannot be protected from thrown objects with personal protective equipment. Operators of machines doing the actual cutting may benefit by sufficient protection to stop thrown objects with metal and polycarbonate materials. This is the subject of the new Draft International Standard 11839 "Test method for classification of panel material for thrown objects." However, other operators in machines that work near the cutting action may not have the protection against thrown objects, eg, skidding machines, trucks, loaders, and so forth. Adjacent roadways, structures/housing, and bystanders also present difficulties if exposure and likely thrown objects combine in worst case scenarios.

Warnings, labels, training, and signage are used when other approaches are not feasible or in combination with other approaches. It also depends on who these measures are intended to influence. Warnings, labels, signage and training can influence operators and others who can see, read and understand them. When a sign on the machine reads "Stay back 500 feet" yet you have to be within a hundred feet (~100') to see it on a moving machine, the warning value is limited. Large warning signs with letters over two feet (2') high are impractical to maintain on forest machines. It is extremely difficult to maintain lettering in a woods environment by typical painted warnings. Likewise, an operator's manual is unrealistic when it suggests the operator stop the machine when anyone is within a five hundred foot (500') radius and has violated the "no entry zone." Operator visibility and the need to attend to the work at hand limit what can be expected of an operator. Nonetheless, when operators do see someone trying to contact them or in harm's way, they will stop the machine to avoid injury. Some manufacturers or distributors apparently think such a "force field" relieves them of liability for thrown objects. It is difficult to even specify a distance that would eliminate hazards of all thrown objects given that some can fly great distances, e.g., saw teeth. Wood chips may not be dangerous beyond fifty feet (50') while chunks fly over three hundred feet (300'). The use of an advisory warning of a distance around a machine where there should be no exposure to thrown objects comes far down the list of mitigation efforts needed to prevent injuries. Relying on a distance warning rather than providing appropriate guarding seems a vulnerable position for manufacturers. Who should specify such a warning distance is also a problem when a base machine manufacturer supplies a carrier to an attachment provider who uses cutting components from two or more suppliers. Further complications arise when domestic and foreign companies are involved. The reality is that the best approach seems to be avoiding throwing objects from the machine itself.

Safety Standards

Safety standards for operator protection and machine guarding are applied at the state level (where they exist), the federal level for logging operations, and international standards that are referenced in both state and federal standards. Furthermore, manufacturers of forestry equipment sell in an international market and generally adhere to international guidelines. It is important to recognize that the various standards apply to different stakeholders in the forestry safety picture. OSHA and state safety standards generally apply to employers and include a mandated enforcement component. Equipment manufacturers, on the other hand, are guided by consensus standards. In the US, forestry equipment standards are developed by the Society of Automotive Engineers (SAE) and define generally accepted practices. At the international level, the International Organization for Standardization (ISO) develops global consensus standards. Consensus standards are voluntary and compliance is at the manufacturer's discretion. The forest equipment industry further complicates the issue as multiple manufacturers may be involved. For example, the base machine may be built by an excavator manufacturer and then converted into a forestry application by a third party company or even the end-user.

Federal Occupational Safety and Health Administration (OSHA) standards apply to all employers in the US unless superseded by approved state-level safety codes. OSHA addresses general machine guarding: "One or more methods of machine guarding shall be provided to protect the operator and other employees in the machine area from hazards such as those created by point of operation, ingoing nip points, rotating parts, flying chips and sparks."(1910.212(a)(1)). Furthermore, "The point of operation of machines whose operation exposes an employee to injury, shall be guarded." (1910.212(a)(3)(ii)). The logging operation codes on guarding require: "Each machine used for debarking, limbing and chipping shall be equipped with guarding to protect employees from flying wood chunks, logs, chips, bark, limbs and other material in accordance with the requirements of subpart O of part 1910"(1910.266(f)(8)(ii)). Subpart O refers to shop and plant industrial processes that are difficult to relate to logging operations but employers have the general obligation cited above. In the federal codes covering logging operations, protective structures address the hazards of material falling, dropping or jill-poking into the cab area rather than thrown objects. The basic content of the federal code covering logging operations comes from the mid 1990's when machine cutting/mulching was much less than now.

Oregon has adopted a more definitive Logging Safety code. The Oregon Forest Activities Code has had three major revisions since 1980 with latest rule changes affecting operator protection current to 2008. Unlike most states, Oregon's code not only covers logging operations but many other forest operations where cutting/mulching machines are used: site preparation, fuels reduction, silvicultural treatments, and so forth. However, the definition of "Operator Protective Structure" lists "whipping saplings, branches, jill-poking and snapping winch lines….and other hazards" (437-007-0025 Definitions). Later standards specify when the need for protection is required: "**(1)** Cabs and protective structures for machine operators must be: **(a)** Provided when machine use exposes an operator to hazardous conditions.(437-007-0770 Protective Structures for Operators, General Requirements)**.** The federal requirement for enclosed cabs for forest machines is more specific in Oregon standards: "**(7)** Each machine used in forest activities that is manufactured on or after July 1, 2004, must have a fully enclosed cab for the operator which prevents objects from entering the cab."(437-007-0775 Protective Structures For Operators, Machines Manufactured On Or After July 1, 2004). Many of the Oregon standards reference national or international standards of performance (SAE or ISO) for guarding and protection. Oregon standards do not specifically address the hazards of thrown objects as discussed above. The Oregon code advisory committee is aware of the hazards of thrown objects but has not suggested standards changes as of this date.

International safety standards for forestry machines are found in ISO 11850 "Machinery for forestry—self-propelled machinery—safety requirements." In section 5.2.2.3 it states that, "operators shall be protected from hazards caused by failed saw chains, teeth and similar failures using polycarbonate or equivalent glazing, or other appropriate guards or shields, or both." Two further documents are under development. ISO 11839 specifies a test method to classify panel material that may be applied to protect machine operators from thrown saw teeth. The intent is to provide manufacturers with quantitative information about the ability of materials to resist impact failures. The problem of chain shot protection is different and the ISO committee has determined that the preferred approach is to catch broken chain in a way that minimizes the whiplash effect. This is being specified in ISO 11837 "Machinery for forestry – Saw chain shot guarding systems – Test method and performance criteria". The scope of the ISO forestry committee limits work to the design of the equipment itself and thus does not address worksite management or other safety approaches noted above.

Summary

Thrown objects are a relatively new hazard in forest operations. As described in this paper, there are many potential incident scenarios that present unique challenges to engineers and safety professionals. In the international arena, work is underway (though not complete) to establish standards to protect operators of cutting and mulching machines. Equipment manufacturers and material suppliers are working on developing improved glazing materials and cab enclosures based on current research. State and federal logging safety codes must develop appropriate worksite direction for appropriate machine guarding and work practices to alert operators and others to the hazards. The Federal Logging Safety section of OSHA does not adequately address this new hazard and should be revised. The concept of a "no entry zone" of a specified distance, e.g. 500 feet, is unrealistic for many forest operations. Cooperative efforts from all involved to improve machine design followed by enforcement, training and warnings would seem to be the most effective.

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