Advantage
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Contents

Factors that influence stem damage caused by harvester heads

Abstract

In response to industry concerns over stem damage caused by harvester heads, FERIC has investigated the head characteristics that are responsible. Although many factors contribute to stem damage, the following are particularly significant: the means of transferring the feed force to the stem, the amount of friction between the stem and the harvester head, the feed roller or track suspension, and the feed roller resistance and slippage. The report summarizes the desirable characteristics of feed devices and provides recommendations on how to select a feed device for various products.

Keywords:

Stem damage, Harvester heads, Feed rollers, Feed tracks.

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Introduction

When the first processors with feed rollers began working in Swedish forest operations in the early 1970s, sawmillers immediately noticed a reduction in sawlog value as a result of damage caused by the spikes on the feed rollers. Despite three decades of feed-roller development, stem damage caused by the rollers remains an issue with harvesters and processors. With the growing use of cut-to-length harvesters in eastern Canada, FERIC has been asked by our member companies to assess the significance of stem damage caused by harvester heads. This report reviews published information on this topic, along with observations collected by FERIC during various field studies.

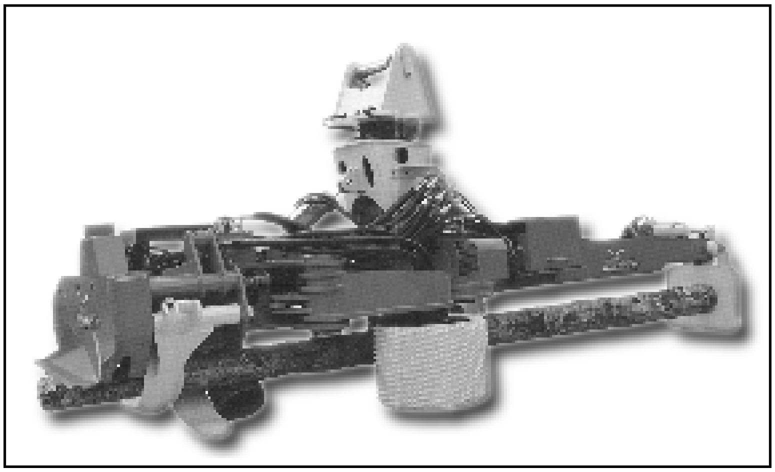

Figure 1. Typical steel feed rollers with conical spikes.

Early work

In 1970 and 1972, the Swedish Forest Products Laboratory (AB Trätek) held conferences intended to help forestry machine manufacturers improve the design of feed rollers and of mechanized felling and cross-cutting devices. Helgesson et al. (1972) reported the results of many feed-roller tests, and noted that three different spiked steel rollers (Figure 1) damaged stems to an average depth of 10 mm and to a maximum depth of 14 mm in forest operations. A solid rubber roller with studs caused very little damage, but users did not accept it because of high costs and poor traction when the bark was loose.

Manufacturers developed several different steel rollers that were able to reduce damage levels, but they could not completely eliminate damage. Rottne Industri AB later introduced an air-filled rubber feed roller that worked well in their two-grip processor (Figure 2). Aktiv Doroverken also introduced a solid-rubber feed roller, but the rubber failed and traction was poor. Skogsarbeten (Sondell 1978) extensively compared the stem damage caused by various types of rubber and steel rollers, and reported that spiked rollers penetrated from 2 to 17 mm into the stem, whereas rubber rollers caused no visible stem damage.

Figure 2. A Rottne two-grip processor with air-filled rubber feed-roller tires.

Rubber rollers obtain their traction from the bark, but the amount of traction between the rollers and the bark is not always adequate; moreover, the bark, which transfers the feed force to the stem, can separate from the stem, particularly in the spring. Various types of chains have been added to rubber rollers to improve traction, and although the chains work, they increase the level of stem damage (typically to a depth of about 4 mm). As well, branch stubs often puncture air-filled rollers, and only very dense and expensive net chains can protect these rollers against punctures. Early solid rubber rollers were damaged less often by branch stubs, but tended to slip more than air-filled rollers. Overall, both types of rubber roller had relatively short working lives.

On single-grip harvesters, spiked steel rollers were used first, because these machines worked primarily in thinning and produced few sawlogs. Although modern spiked feed rollers cause less damage than the models used in the 1970s, they still produce more damage than rubber rollers. This is an important issue for some sawmills, since harvester heads have now grown sufficiently large and powerful to handle trees capable of producing sawlogs. Because of the potential for damage, rubber rollers became more common, and today, the use of rubber rollers is widespread, with Sweden being the implementation leader. Over the years, the working life and traction of rubber feed rollers have improved, but spiked steel rollers have not disappeared because

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they are usually cheaper and provide much better traction than rubber rollers. Steel rollers in the shape of an hourglass have been tried, but the design was abandoned because of poor delimbing and feeding of crooked trees, and problems with stem breakage when delimbing small stems. AB Trätek first tested a track-feed system as an alternative in 1974 and found that tracks could provide higher tractive effort than steel feed rollers (Helgesson and Wiklund 1974), but single-grip harvesters with tracks began to appear only in the middle of the 1980s (e.g., on Keto, Lako, and Silvatec heads).

Harvester-head parameters that affect stem damage

Feeding devices

Steel feed rollers

Steel feed rollers have a cylindrical surface to which traction-improving devices (i.e., various types of spikes) are welded. Long, slender spikes create deep holes in the stem, so most manufacturers use short crosswise ribs, or elliptical or rapidly widening spikes, to limit penetration (Figure 3). Often, a generous weld at the point of attachment for the spike or rib limits the depth of penetration. Steel rollers are durable and some even last the lifetime of the harvester head. FERIC visited one machine that had operated for 8000 hours, with the original feed rollers still in good shape.

In field studies, FERIC measured penetration of the stem caused by three heads that used steel feed rollers (Table 1). The sample included a Timberjack 762B head working in black spruce with an average stem volume of 0.12 m^3, and two Pan 828 heads working in first thinnings of spruce with average stem volumes of 0.04 m^3. Pieces of chain made from square stock had been welded to the surface of the steel rollers on the Pan heads.

Rubber feed rollers

Typical modern rubber feed rollers use an 8- to 10-cm-thick layer of vulcanized rubber on a steel cylinder, with traction chains covering the rubber (Figure 4). The degree of compression stress is critical to determining the rubber's durability; increasing compression force to improve feed force decreases roller life. Large rollers can endure

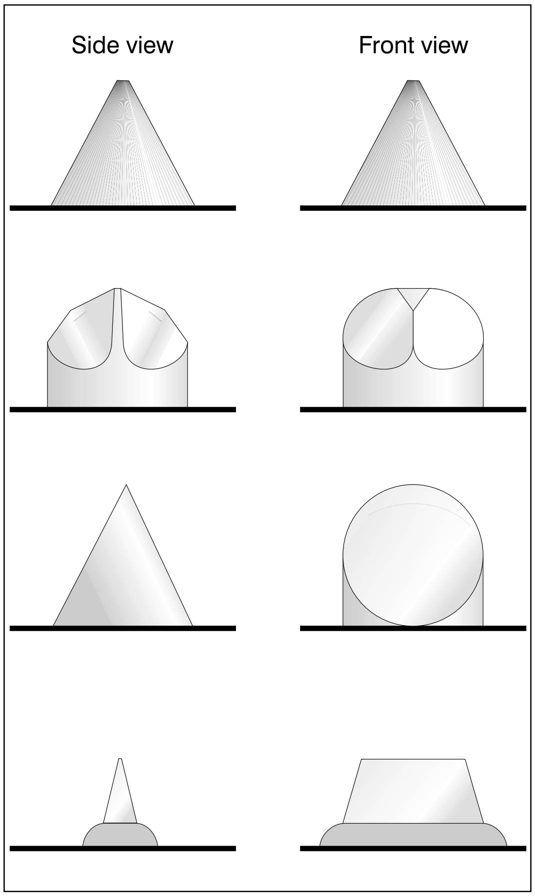

Figure 3. Commonly used spikes in steel feed rollers.

Table 1. Examples of stem damage caused by steel feed rollers

	Average stem volume (m^3)	Average depth of stem damage (mm)	Maximum depth of stem damage (mm)
Timberjack 762B head	0.12	2.0	10.3
Pan 828 head	0.04	3.5	7.0
	0.04	3.6	8.0

higher compression forces than small rollers, and computer-controlled compression force can decrease the average fiber stress in the rubber and thus increase roller life. Compression force is initially set low, but when the computer detects spinning, it increases the pressure. Various users of rubber rollers have indicated to FERIC that the life of rubber rollers can exceed 2000 hours. Small-diameter stems travel more than larger stems along the inner edge of the roller, thus increasing wear at this location, but most feed rollers can be rotated so as to prolong their life.

Feed speed decreases when the protective chain rolls between the stem and the rubber, when chains slip on the bark, and when the rubber compresses. Because tight chains roll less than loose chains, operators should regularly check and adjust the chain tension. Feedrollers that use chains with hourglass-shaped links in a diamond pattern (Figure 4) have been shown to provide better traction than rollers with crossed chains made from straight links of square stock in one Swedish test (Myhrman 1998). One manufacturer uses a harder rubber against the drum and a softer layer on the outer surface to reduce roller compression. But despite improvements in rubber rollers, steel feed rollers still provide better traction and longer roller life.

Figure 4. Rubber feed rollers and a diamond chain pattern with hourglass-shaped links.

FERIC observed three heads with rubber feed rollers at work, all of which used crossed single-strand chains on the rubber roller. Two Timberjack 762B heads were harvesting large lodgepole pine in Alberta. Their rollers had worked about 2000 hours and were in need of replacement; the chains had worn themselves about 4 mm deep into the rubber. Delimbing of large trees (>0.5 m^3) was difficult because of slippage on the bark and the large size of the branches. When the rollers spun, they dug about 6 mm into the stem before feeding stopped. When this occurred, the operators had to assist the feeding by swinging the boom and opening the delimbing arms slightly.

FERIC also visited an operation in which a Timberjack 762B head equipped with rubber feed rollers was working in 0.12-m^3 black spruce near Chapais (Quebec). The original rubber rollers had lasted 1 year in this two-shift operation. Since then, the contractor had tried locally vulcanized rollers, but their working life had only been 3 to 4 months. The lower parts of the stems were generally free of damage, but some stem damage less than 6 mm deep was observed where the rollers had spun out at limb clusters or bends in the stem. The average depth of damage was 0.4 mm, but up to 3.2 mm was measured in some cases (spinouts excluded).

Other feed devices

Several manufacturers offer feed rollers that increase the contact area with the stems. For example, Grangärde offers a roller with triangular steel bars, in which two sides of the bars are supported against rubber cushions on the periphery of the roller and the third side, which is equipped with spikes, contacts the stem. Ponsse's rollers include several plates with studs mounted on a rubber bed. Tests of the prototype by Trätek showed that about 10% of the stem damage by these rollers was deeper than 4 mm (Helgesson 1997), although the production version had less than 1% of the damage deeper than 4 mm (Helgesson 1998b). Moipu feed rollers are made of rubber, with studded steel plates fastened to the rubber with chains (Figure 5), and contractors have used these rollers successfully in Finland and in northern Wisconsin. Tests have shown that the Moipu feed rollers provided 40% higher feed force with low stem compression pressure than rubber feed rollers equipped with chains, but only 10% higher feed force at high compression pressures (Voutilainen 1997). Although FERIC found no studies on stem damage, it is likely that the rubber under the plates (Figure 5) would reduce turning of the spikes in the wood and increase contact area.

Currently, all Keto and Steyr heads, the Ponsse H60, and some Silvatec and Logset models use tracks to feed the stems. Keto is so confident in the traction provided by its tracks that it mounted the length-measuring sensors on the tracks' motor shafts. One advantage of tracked feeding systems is that they can provide a very large contact area in a small space without increasing the width of the head as much as large feed rollers would. Tracks are also available with different heights of ribs. Because operators can change tracks quickly, and the tracks take up little storage space and are much less expensive than feed rollers, operators could conceivably switch track configurations for different jobs. In a FERIC study of Keto tracks (Makkonen 1998), the maximum penetration depth during the spring was consistently less than 4 mm with a shallow-rib track, versus 9.5 mm with another track that used aggressive ribs.

Harvester heads with stroke-type feeders are slow, but produce a high feeding force (e.g., Arbro, Tapio 400, Patu 400SH). FERIC measured the depth of stem damage on a log processed by an Arbro harvester, and found that the delimbing arm itself had caused very little damage; however, the grab arm that held the tree during delimbing had caused an average penetration of 3.8 mm and a maximum penetration of 9 mm.

Figure 5. The Moipu feed roller.

Transmission of feed force to the stem

The force generated by the feeding device (rollers or stroking devices) must be sufficient not only to cut limbs, but to move the tree through the head and overcome friction. A net delimbing force of 15 kN is sufficient to cut most large limbs on coniferous trees (Myhrman et al. 1995a). However, feeding trees is inefficient and the *net* forces that have been measured in Swedish studies have only been 40 to 70% of the *gross* values reported by manufacturers; for example, a harvester with a 24-kN gross feed force could have a net feed force of only 10 to 17 kN (Landström et al. 1996). This decrease is partially caused by energy losses within the hydraulic system (Myhrman et al. 1995b), but slippage (spinout) of the feed rollers also often limits the feed force.

The net feed force depends on the pressure of the feed device against the stem and on the traction this pressure generates between the feed roller and the stem. In general, the compression force varies from 10 to 30 kN (Helgesson 1998a). The harder

In designing a feed roller, there is a tradeoff between feed force and stem damage: increasing the feed force beyond a certain point increases stem damage unacceptably.

the feed roller presses against the stem, the higher the feed force, but extreme compression can damage (and perhaps even shatter) the stem, and this limits the amount of pressure that can be applied. Ribs, spikes, and chains that penetrate the bark and wood improve traction, but also increase stem damage. Spikes that are in contact with the stem during feeding change their angle with respect to the stem as the roller rotates, and this tears the fiber; long spikes and a small roller diameter increase the magnitude of this effect. If the aggressiveness of the traction-improving device must be limited so as to reduce stem damage, using a larger contact area between the feed device and the stem or using a higher compression force can compensate for the reduced penetration. For example, some manufacturers have added feed rollers (e.g., the Fabtek Series 2000), have used feed rollers with larger diameters (e.g., the Hornet 825), have selected longer tracks (e.g., Keto, Ponsse), or have increased compression pressure (e.g., Valmet and SP-Maskiner use variable compression pressure). The Fabtek Series 2000, Ponsse, Logset, and Patu heads have two feed rollers in each arm to obtain a larger contact area than is possible with a single large roller. However, the second roller follows the path of the first roller and likely has less traction on the broken surface produced by the first roller.

Ideally, the bark transfers the feed force to the stem, but the strength of the bark's adhesion to the stem varies during the year and varies by species; thus, bark strength is often inadequate, especially in the spring. Where this is the case, traction devices must penetrate the wood to some extent if they are to provide adequate feed force.

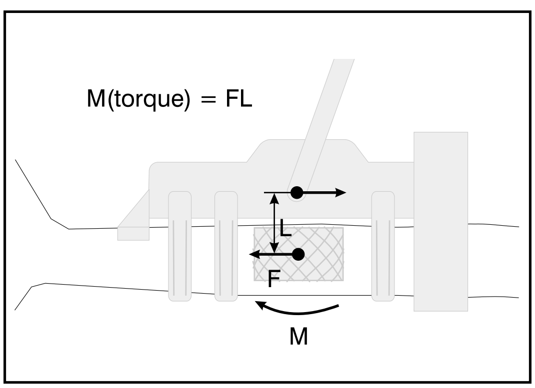

Figure 6. Because the head's pivot point is above the feed roller's point of contact with the stem, the head tilts and the fixed delimbing knife could lose contact with the stem.

Friction between the stem and the harvester head

When the stem passes through the head, it rubs against the head's frame and the delimbing knives, and thus part of the feed force is lost to friction. The magnitude of these frictional losses is 1 to 3 kN (Granlund et al. 1996, 1997). The lower the friction, the less feed force needs to be transferred to the stem; consequently, stem damage can be reduced by reducing friction. Free-wheeling rollers are often used in the frames of harvester heads (one to six rollers) to reduce this friction, and Steyr has mounted free-wheeling rollers in the delimbing arms to help accomplish this goal.

The acceleration and deceleration of the stem during delimbing, plus the friction of the stem against the ground, create a torque about the pivot point of a dangle head (Figure 6). This force causes the upper moving knives and the lower end of the frame to press against the stem, with an estimated contact force of 1 to 4 kN that further increases friction. (Swinging the machine's boom in the direction opposite to the feeding direction during delimbing can reduce this friction component as well as the force required to move the tree.)

Feed-roller resistance

Some traction is lost when stems and rollers deform during feeding. This loss is known as "feed-roller resistance" and it contributes to stem damage by increasing the feed force required. SkogForsk estimates the resistance of rubber rollers to be about 10% of their compression force (Granlund et al. 1996), which amounts to 4 to 7 kN. One steel roller tested by SkogForsk (Myhrman 1998) showed the highest efficiency of transmitting the feed force (82%) of all tested devices (others ranged from 56 to 76%; Landström and Myhrman 1996), and this suggests that steel rollers could have lower feed-roller resistance than rubber rollers. Increasing the contact surface and decreasing the compression force would reduce stem deformation and would thus decrease feed-roller resistance. High compression force also tends to break loose the bark, especially in spring.

Feed-roller or track suspension

The suspensions of feeding devices can lift the stem against the fixed delimbing knives and the frame during delimbing. This lifting force takes the weight off the movable delimbing knives and reduces the forces on the knives, thereby reducing losses to friction. Several suspension systems and their influence on stem support and compression are described below.

With simple swing arms that pivot near the top of the head (e.g., Timberjack 762, Votec, Denharco SH-500, Ultimate, Grangärde, Silvatec, Rottne, and Rotobec heads), the traction force increases compression against the stem more for small stems than for large stems (Figure 7, top). This feature can increase feeding efficiency because the compression force adjusts to the feeding resistance by itself. The increase in compression force can vary from 2 to 10 kN, depending on tree diameter, delimbing force, and suspension geometry. By carefully selecting the dimensions of the suspension elements in relation to the feed force, the maximum compression force remains fairly constant for every tree diameter.

When the roller arms pivot near the bottom of the head (e.g., Thor, Caterpillar, and some old Rottne models), the force from motor torque on the swing arm reduces the contact force between the rollers and the stem for stem diameters smaller than the distance between the pivot points of the arms (Figure 7, bottom). The feed force increases for diameters larger than the distance between the pivot points. The maximum compression force is larger for large diameters than for small diameters. The feed

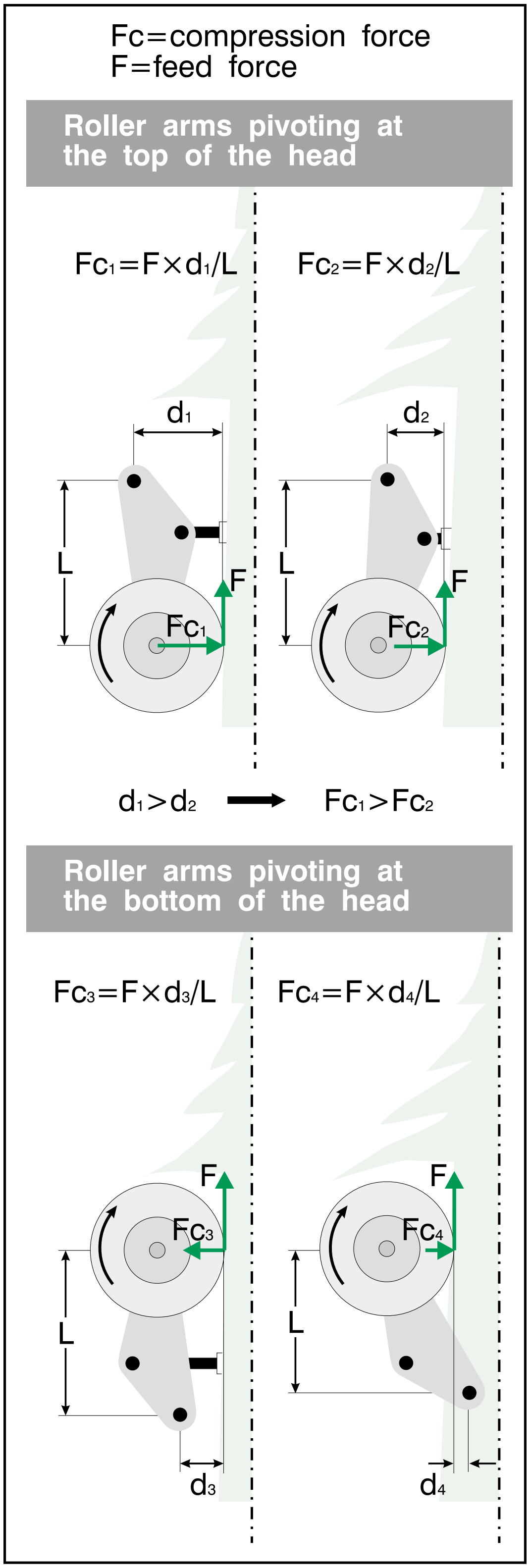

Figure 7. With roller arms that pivot at the top of the head (top) the feed force increases compression more for small stems than for large stems.

When the arms pivot at the bottom of the head (bottom) the feed force reduces compression for stems smaller than the distance between the pivot points. For large trees, the larger the tree the greater the compression force.

force does not influence the roller compression force when the pivot shafts of the arms (e.g., Denharco HP-550, Timberjack 745, Ponsse, and Logset heads) or the shafts of dual-arm pivots (e.g., Keto and Valmet) are parallel with the tree in the head.

Roller or track suspensions differ in the extent to which they support the tree (fully, partially, or not at all) when the head is in the delimbing position. If the feed rollers or tracks do not support the tree, the weight of the stem rests on the delimbing knives, thereby increasing the friction between the tree and the head. When two rollers are mounted parallel to each other where they contact the sides of the stem, the weight of the tree falls completely on the movable delimbing knives (e.g., Timberjack 762, Timbertech RTL-95, and Keto heads; Figure 8A). When the two rollers angle inwards, the rollers partially support the stem (e.g., Ultimate 5620, Lako 550, and Fabtek Series 2000 18' heads; Figure 8B). When the roller's inward angle increases with increasing tree diameter, the rollers support large trees more than they support small trees (e.g., Timberjack 762 B and C, Votec Tree King, Denharco SH500, and new Valmet heads; Figure 8B). The new Valmet heads have a dual-arm suspension system that determines the inward angle of the rollers and thus the lifting-force ratio for each diameter (Myhrman et al. 1998). Swing-arm designs with a pivot pin parallel to the stem (e.g., Ponsse H60 and Logset heads; Figure 8C) provide more support for small stems than they provide for large stems. Thus, they often feed small stems with excessive friction.

Triple-roller designs (e.g., Denharco DH-550, Waratah, and Ponsse H53 and H73 heads; Figure 8D) and four-roller designs that contact the tree from different directions (e.g., Timberjack 745 and 758 heads; Figure 8E) support the tree partially with their rollers and thus, can use lower pressure on the delimbing knives. Although multi-roller heads seem to suspend the tree on the rollers alone, some components such as the delimbing knives must counter the turning moment about the head's pivot point caused by feeding the tree through the head. Some heads have all four rollers pressing the stem against the head frame (e.g., Lako 550 4wd and Logset 5-55 heads) and the required knife pressure depends very strongly on the angles of the feed rollers against the stem.

Another important feature is the head's capacity to feed a crooked tree. The knives and feed rollers must permit easy shifting of the knives and rollers away from a symmetric position. For a tree to pass through the head without additional friction, the compression force exerted on its stem by the delimbing knives and the feed rollers should not change when the positions of these components of the head change. Unfortunately, the compression force depends on the arm position for all current heads.

The literature review FERIC conducted found no comparisons between two-roller heads and heads with more rollers in terms of stem damage as a function of feed force. Thus, it is difficult to make recommendations for different operations. However, if an operator wants to use rubber rollers, a two-roller head is preferable because rubber rollers must have large diameters to achieve acceptable life. Steel rollers are more suitable for multi-roller heads, as their working life is nearly independent of roller size. Adding steel rollers improves traction, but very small steel rollers need aggressive traction elements that cause considerable stem damage. When more than two rollers are distributed around the stem, the load on the rollers becomes unequal and varies with different stems; thus, the heads require devices to synchronize feed-roller speed. Several feed-roller arrangements are described in Figure 8 and Table 2.

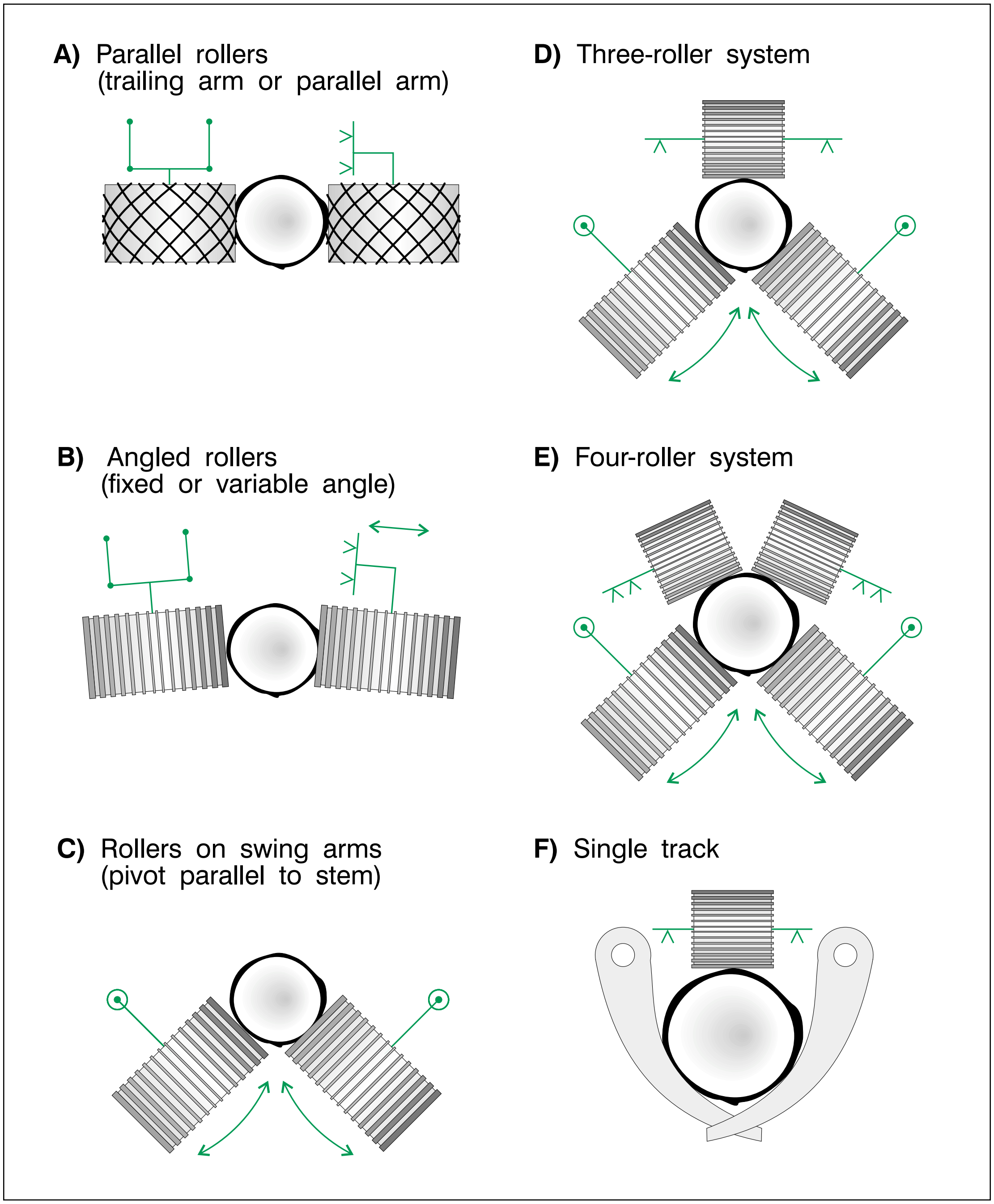

Figure 8. Feed-roller arrangements with the felling head in a horizontal position. Technical details of each arrangement appear in Table 2.

Feed-roller slippage

If a feed roller or track spins on the stem, it can cause severe damage to the underlying wood. During field studies, FERIC has observed that when the feed rollers spin, they can grind away as much as 6 to 8 mm of wood in a very short time. The harvesting computers of modern machines often monitor the feeding speed, and when spinning occurs, the computer stops feeding much faster than an operator could do. Thus, the damage caused by spinning rollers is reduced. The simplest systems stop feeding when no signal is received from the measuring wheel during a predefined time. More advanced arrangements monitor speed

Table 2. Feed roller and track arrangements

	Head example reference number[a]								
	1	2	3	4	5	6	7	8	9
Reference letter (see Figure 8)	A	A	B	B	B	C	D	E	F
Roller in arms	X		X	X	X		X	X	
Roller in frame							X	2	
Track in arms		X				X			
Track in frame									X
Swing arms	X		X			X	X	X	
Parallel arms		X		X	X				
Setup of the arm pivots varies with the roller contact angle to support the stem			X	X					
Feeding changes the compression force	X		X		X				
Feeding does not change the compression force		X		X		X	X	X	X

[a] Examples for each arrangement: **1.** Timberjack 762, Logmax GM 650, Silvatec 445, Hornet 825, and Fabtek FT 180. **2.** Keto (all models). **3.** Timberjack 762B and C, Denharco SH 500. **4.** Valmet (recent models). **5.** Lako 450, 550, and 650. **6.** Ponsse H60 and Logset 6-55. **7.** Denharco DH 550, and Ponsse H73 and H53. **8.** Timberjack 745 and 758. **9.** Steyr processors.

differences between the feed rollers and the measuring wheel. Some harvester computers (e.g., the computer for SP 551 harvester heads) let the operator perform an initial adjustment of the compression force as a function of stem diameter and species using a proportional pressure-control valve in the head. The computers also provide more gradual acceleration and deceleration to further limit slipping. With some systems (e.g., Motomit 4), delimbing can extend slightly beyond the bucking point, after which the rollers move the stem back to the appropriate bucking point. This provides a short stem section with no branches that facilitates acceleration and delimbing of the next bolt.

Conclusions

Several factors related to harvester head design affect the potential for stem damage during processing. These include the type of feeding mechanism, feed force, friction in the head, the feed device's suspension, and feed-roller resistance and slippage.

Steel rollers last long and offer good traction, but can cause considerable damage to the stem. This may be less of a problem for pulp logs, but can pose a serious problem with sawlogs. Rubber rollers cause negligible stem damage, but their working life has been short and they tend to slip excessively during the bark-slip season. Using diamond-shaped chains on rubber rollers offers better traction than using cross chains. Various other roller designs combine steel and rubber and fall between steel and rubber rollers in terms of performance and stem damage. Feed mechanisms based on tracks have shown good traction, and the relatively non-aggressive ribs on tracks cause only slightly more stem damage than rubber rollers. Stroke-type feeding devices have a high feeding force, and the ribs in the grab arms can be easily modified if necessary to reduce stem damage.

Stem damage also depends on roller and delimbing knife pressures, on the computer's ability to adjust compression pressure, on the extent to which feeding resistance increases penetration into the stem, and on the feed device's ability to control slippage. Increasing the compression force improves traction, but also results in greater stem damage and faster wear of components (especially of rubber rollers). Many different feed devices are available, and users should select a product that produces acceptable damage levels for their particular operation. Moreover, in assessing the severity of stem damage from harvester heads, don't forget that debarking at sawmills also damages logs because many debarking machines have aggressive feed rollers and debarking knives (Mäkelä and Yli-Hukkala 1995).

Implementation

The following features of harvester heads usually reduce the risk of stem damage:

- A large contact area between stems and the feed device; this can mean large-diameter feed rollers, a large number of feed rollers, long tracks, or stroke-feeder grab arms with a large contact area.
- Shallow traction-enhancing devices on feeders; a high density of crosswise ribs or spikes that widen rapidly towards the base; tight chains on feed rollers to reduce slippage induced by rolling of the chains.
- Low friction of the stem against the head's frame; rollers in the frame or the delimbing arms. The feed device should carry part of the weight of the tree to reduce friction against the delimbing knives.
- A short distance between the feed device's point of contact with the stem and the head's pivot point, and a long distance between the delimbing arms and the head frame's bottom (roller) to minimize contact forces that result from tree acceleration.
- A computer system that stops feeding when spinout occurs.
- A feed system that accelerates and decelerates the stem gradually.
- Automatic adjustment of the compression force of the feed device.

Table 3 summarizes these features in terms of the desirable head properties for various types of wood product.

Table 3. Recommended characteristics of the feed device for various types of products

	Desirable characteristics
Hardwoods	• a large head with a topping saw • the most aggressive traction devices permitted by the client and end-product (high traction is required by the difficulty of delimbing many hardwoods) • the ability to handle crooked or forked stems
Pulpwood	• a head large enough to handle the expected branchiness of the stems being harvested (larger heads provide greater feed force) • the most aggressive traction devices permitted by the client and product (because of the difficulty of delimbing larger trees)
Sawlogs or veneer logs	• a large contact surface for the feed device, combined with non-aggressive traction devices (e.g., relatively short spikes, large rubber rollers with diamond-shaped traction chains) • computerized control of compression pressure • relatively gentle acceleration and deceleration • control of spinouts to avoid gouging the wood

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