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INFLUENCE OF SAW CHAIN TYPE AND WOOD SPECIES ON THE KICKBACK ANGLE OF A CHAINSAW

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Abstract

Wood processing operations, in particular debarking, can pose a significant hazard for the chainsaw operator when performed without due caution. The most common hazards with potentially fatal consequences include kickback which occurs when the chainsaw's guide bar is violently thrown backwards towards the operator. The aim of this study was to determine the influence of wood species and different saw chain brands on the kickback angle of a chainsaw. The kickback angle of a combustion chainsaw was analyzed in a self-designed test stand with the use of a digital level gauge accurate to 0.1°. Four differently priced saw chain brands, including two standard chains and two chains with anti-kickback features, were evaluated. Kickback was analyzed on five wood species (pine, spruce, birch, alder and oak) at three engine speeds (50%, 75% and 100% of maximum rotational speed). Kickback was significantly determined by wood species and saw chain type, and it was less influenced by the rotational speed of the chainsaw engine. The average kickback angle was largest in alder and smallest in spruce. The analyzed parameter was not always reduced by saw chains with anti-kickback features. In some cases, low-priced saw chains with anti-kickback features offer less protection than more expensive standard chains. Chainsaw buyers should decide whether it is worthwhile to compromise on safety in exchange for a lower price.

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Introduction

Around 90% of wood harvesting operations in Poland are performed with the use of portable chainsaws (DĄBROWSKI 2004, MACIAK 2011). Chainsaws are widely used by both professional loggers as well as amateurs for performing minor tasks in construction sites, farms and home gardens (DĄBROWSKI 2012). A chainsaw consists of a saw chain that rotates along a guide bar. The saw chain is an exposed element which poses a considerable threat for the operator and his immediate surroundings. The majority of accidents involving chainsaws result from direct contact with a moving saw chain (KOEHLER et al. 2004, MALINOWSKA-BOROWSKA et al. 2012, WÓJCIK 2013, ROOB, COCKING 2014). To minimize that risk, modern chainsaws are equipped with anti-kickback features (DĄBROWSKI 2004, 2009, KALJUN, DOLŠAK 2012, TOMCZAK et al. 2012, WÓJCIK 2012). These include right and left hand guards, a chain catcher and a chain brake. The left hand guard protects the hand on the front handle, and it is integrated with the brake lever which stops the chainsaw (the brake is activated by the operator or automatically when the chainsaw kicks back). The right hand guard prevents a dislocated or broken chain from being thrown back to the hand on the front handle. The chain catcher is positioned underneath the chainsaw body in front of the clutch, and it serves a similar purpose. The most important safety feature is the chain brake which is activated by the operator or automatically when the guide bar kicks back. Kickback occurs when the tip of the guide bars comes into contact with a hard object, such as wood (BOWERS, RIPPY 2009, MACIAK 2009, DĄBROWSKI 2012, WÓJCIK 2013, ARNOLD, PARMIGIANI 2015). The saw chain comes to an abrupt stop or becomes wedged in the processed material, and the guide bar is thrown back towards the operator. The chainsaw rotates around its axis, and the cutting assembly poses a significant hazard for the operator. According to standard PN-ISO 6335-1999, mean chainsaw brake time should not exceed 0.12 s, and it should not exceed 0.15 s in any trial. The brake immobilizes the saw chain when the cutting assembly is thrown towards the operator, which minimizes the risk of serious injury. According to WIĘSIK (2001), kickback energy is determined by the moment of inertia of the power transmission system (engine, flywheel and clutch) and the cutting assembly, angular velocity of the crankshaft immediately before impact, and angular velocity of the crankshaft at which the clutch is disengaged. Kickback can be completely eliminated by sheathing the guide bar tip, but this solution compromises performance because it reduces active cutting length and prevents plunge-cutting (WIĘSIK 2001, WÓJCIK 2013). Chainsaws with the above modification of the cutting assembly can be used to perform minor tasks, but are not suited for professional use in forestry.

Kickback risk can be minimized by dispersing the generated energy. This can be accomplished by firmly grabbing the handle and assuming a proper body position during operation (BOWERS, RIPPY 2009). Kickback is a rapid event which is usually not anticipated by the operator. For this reason, anti-kickback features are the key to the safe use of a chainsaw. In chainsaws with safety features, chain links have a different design. The depth gauge in front of each cutter has a special profile, and drive links and tie straps have higher pitch (DĄBROWSKI 2004, TOMCZAK et al. 2012). Chainsaws with low-profile chains have emerged in recent years. Cutting teeth and tie straps have an oblique profile in the rear part of the sliding surface, and the resulting clearance between the tooth and the guide bar dampens vibrations and decreases kickback energy.

The factors which significantly influence kickback angle and kickback energy have been exhaustively discussed by DĄBROWSKI (2012, 2015). They include engine power and rotational speed, length of the guide bar, radius of the guide bar tip, type of saw chain and its geometric parameters, chain tension, sharpness of cutting teeth, chain brake effectiveness, temperature and moisture content of wood, position of the saw chain relative to the direction of wood grain. Kickback risk increases with an increase in engine power (displacement). Amateur operators should opt for chainsaws with smaller engines and smaller potential kickback angle, even at the expense of lower cutting performance. Professional loggers should also choose chainsaws that are best suited for the performed tasks to avoid working with heavy equipment and to minimize the risk of kickback (DĄBROWSKI 2012).

The length of the guide bar should also be appropriately selected for the task at hand. The longer the guide bar, the smaller the kickback angle. A longer guide bar decreases the moment of inertia of the cutting assembly and moves the cutting force away from the engine; therefore, a large portion of the chain's kinetic energy is absorbed in the cutting process. According to the literature (DĄBROWSKI 2012, 2015), kickback energy accounts for only 2% to 11% of the chain's kinetic energy, but it can still have very dangerous consequences for the operator. In practice, very long guide bars do not serve a useful purpose. They add to the chainsaw's weight and make it more difficult to operate. In extreme cases, engine power may be insufficient to effectively perform a cutting operation. Guide bars with a tapered end and small nose radius, preferably with an armor tip, increase operating safety (MACIAK 2009, DĄBROWSKI 2012).

Kickback is also effectively minimized by the chain break which decreases the kickback angle by around 30–39% (DĄBROWSKI 2012). Chain stopping time is much shorter than the duration of kickback, which indicates that chain breaks are effective and should be installed in modern chainsaws as a standard feature. Some chainsaw brands, in particular log debarkers, are equipped with an additional brake lever by the rear handle (MACIAK 2009, WÓJCIK 2013, 2017). This feature enforces correct posture during operation, and it supports rapid braking during kickback when the operator's hand is thrown back to the brake lever.

According to BOWERS and RIPPY (2009) and TOMCZAK et al. (2012), chainsaw operators can minimize kickback by holding the front handle with the thumb in opposition to the remaining fingers, assuming a correct posture, anticipating dangerous events, initiating the cutting process with the underside of the guide bar, sharpening and maintaining the saw chain in good condition, and using saw chains with anti-kickback features. The appropriate cutting teeth geometry not only increases operating safety, but also improves performance (DĄBROWSKI 2012). For this reason, cutting teeth should be sharpened and maintained with the appropriate tools, and unskilled operators should rely on professional service outlets where saw chains are sharpened mechanically, despite the fact that mechanical sharpening shortens the chain's service life. Operators should ensure that the tension of the saw chain is properly adjusted. There are no universal tensioning guidelines. A correctly tensioned saw chain should adhere closely to the guide bar and move freely around it (TOMCZAK et al. 2012). Proper tensioning significantly reduces the kickback angle (DĄBROWSKI 2012, WÓJCIK 2013). The introduction of automatic chain tensioning systems would greatly reduce kickback and improve performance.

DĄBROWSKI (2012, 2015) states that the use of saw chains with anti-kickback features significantly reduce kickback. There is a wide selection of saw chain brands which differ vastly in price. Buyers are often faced with the dilemma whether low-priced saw chains compromise operating safety. In the literature, most kickback analyses were performed on samples of debarked wood. In practice, the saw rarely comes into contact with debarked wood at the beginning of the cutting process. Kickback occurs mainly during debarking or unskilled attempts at plunge-cutting (MACIAK 2009, TOMCZAK et al. 2012). Therefore, in the first phase of kickback, the saw is usually in contact with bark. For this reason, kickback analyses should be performed on samples of fresh wood, and the surface that comes into contact with the saw chain should not be debarked.

The aim of this study was to determine the influence of wood species and saw chain type on the kickback angle of a chainsaw.

Materials and Methods

The kickback angle of a combustion chainsaw was analyzed in a self-designed test stand (Fig. 1). The test stand was supported by a cradle of cold-formed closed profiles (*2*). A grip matching the shape of the chainsaw's front and rear handles was mounted on bearings in the cradle (*1*). The grip was fastened with cable ties around the top and rear parts of the chainsaw. The grip was connected to a digital level gauge on one side (*4*) and a unidirectional clutch on the other side. The level gauge measured the kickback angle which was modified by adjusting the segments of the loading lever (*9*). A jaw clutch coupling in front

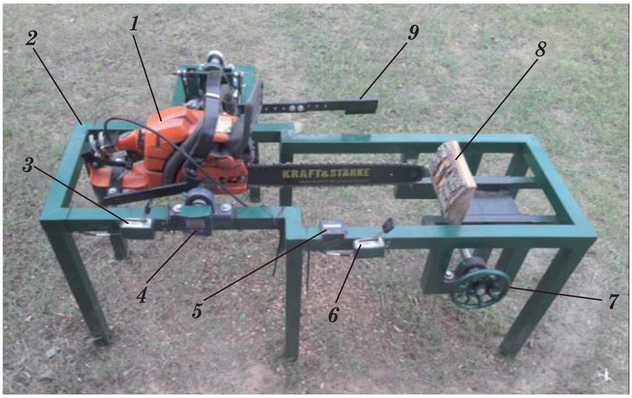

Fig. 1. Test stand for analyzing the kickback angle of a chainsaw: *1* – combustion chainsaw, *2* – cradle, *3* – clutch disengaging lever, *4* – digital level gauge, *5* – digital revolution counter, *6* – lever for controlling engine rotational speed, *7* – handwheel for adjusting the position of the wood sample, *8* – wood sample, *9* – loading lever

of the unidirectional clutch was used to return the chainsaw to its initial position. The wood sample (*8*) was fixed with screws to a shelf whose position relative to the chainsaw was controlled with a handwheel (*7*). The rotational speed of the chainsaw engine was adjusted mechanically with a lever controller (*6*), and it was measured with a digital revolution counter (*5*).

The test stand for measuring the kickback angle was equipped with the Husqvarna 345e combustion chainsaw with a 45 cm^3 engine (2.2 kW). The chainsaw weighs 4.9 kg without cutting equipment, and it provides an idle speed of 2,700 rpm. The recommended speed at full power is 12,500 rpm. The clutch is disengaged at a speed of around 3,700 rpm. The recommended length of the guide bar is 18 to 45 cm. A Kraft & Starke guide bar with a length of 45 cm, nose radius of 23 mm and a 10 tooth sprocket was used in the test stand.

Four saw chains were tested in the study (Fig. 2), including two standard chains (SC-2 and SC-3) and two chains with anti-kickback features (SC-1 and SC-4). The technical specification and prices of the analyzed saw chains are presented in Table 1.

Saw chain kickback was tested on five wood species: pine, spruce, birch, alder and oak (Tab. 2). Wood samples were not debarked to simulate real-world conditions during wood harvesting. The samples were obtained directly from freshly logged trees by slicing off the top part of a trunk with a thickness of around 5 cm with the use of a frame saw. The slices were divided into segments with a length of around 20 cm to produce analytical samples. During the study, the samples were stored in sealed plastic bags to stabilize their relative moisture content. The relative moisture content of wood samples was analyzed in three replications for every wood species with the use of the DampMaster moisture meter (Laserliner, Germany) with ± 3% accuracy.

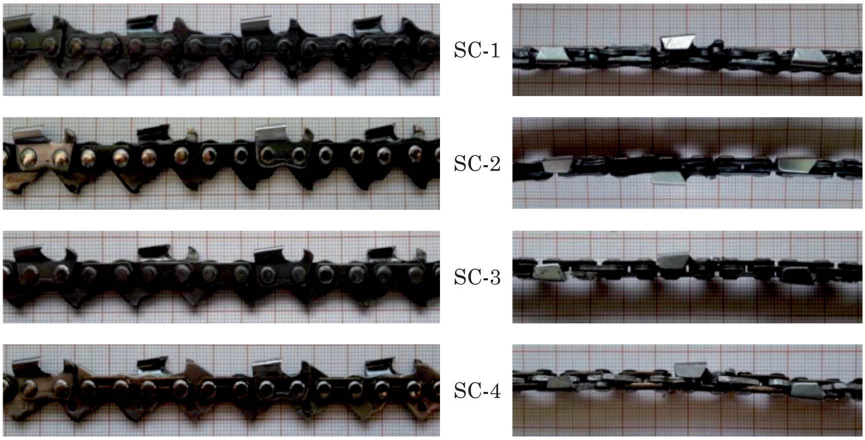

Fig. 2. Tested saw chains

Table 1

Specification of the tested saw chains

Symbol	No. of drive links	Pitch [in.]	Cutting tooth	Thickness of drive link [mm]	Anti-kickback drive link	Price [€]
SC-1	72	0.325	semi-chisel	1.5	yes	12.3
SC-2					no	8.2
SC-3					no	6.8
SC-4					yes	5.6

Table 2

Specification of the analyzed wood samples

Parameter	Wood species				
	pine	spruce	birch	alder	oak
Average trunk radius [cm]	12.5	8.2	21.3	14.0	20.1
Average bark thickness [mm]	3.4	2.4	6.8	6.2	7.2
Average moisture content [%]	58	69	61	63	55

Wood samples were fixed with screws to a shelf in the test stand with the bark-covered side facing the chainsaw. The samples were placed in the test stand by positioning the center of the trunk's radius of curvature around 1 cm higher than the sprocket's axis of rotation. The chainsaw was operated at three different speeds (50%, 75% and 100% of maximum rotational speed), and the wood sample was moved in the direction of the saw chain with a constant speed of around 0.01 m/s until kickback. The kickback angle was measured to the nearest 0.1° with a digital level gauge. Measurements in every variant were conducted in ten replications. Based on the results of preliminary trials, the segments of the loading lever were adjusted to ensure that the kickback angle of the most susceptible saw chain does not exceed 70° (according to standard ISO 9518:1998).

The measured kickback angles were processed statistically in the Statistica PL v. 12.5 program at a significance level of $\alpha = 0.05$. The differences between average kickback angles were determined by factorial ANOVA. Normal distribution in each group was analyzed with the use of the Shapiro-Wilk W test, and homogeneity of variance was evaluated with Levene's test (RABIEJ 2012).

Results

The average values of the kickback angle for every tested variant are presented in Figure 3. The analyzed parameter ranged from 10.3° (spruce, saw chain SC-1, 50% of maximum rotational speed) to 54.9° (pine, saw chain SC-4, 50% of maximum rotational speed). Wood species, saw chain type and engine speed had a varied influence on the kickback angle. The largest kickback angles were most frequently noted during tests performed at maximum engine speed (8 out of 20 cases), on alder samples (8 out of 12 cases) with saw chain SC-3 (8 out of 15 cases). Chainsaw operations performed on spruce samples (8 out

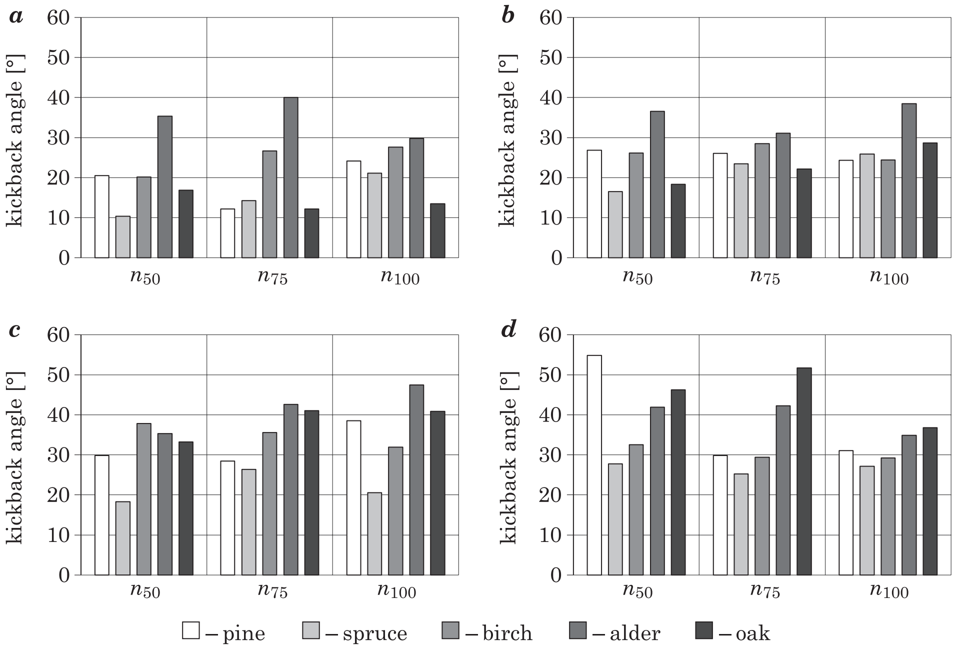

Fig. 3. Kickback angles for different engine rotational speeds, saw chain types and wood species: *a* – SC-1, *b* – SC-2, *c* – SC-3, *d* – SC-4

of 12 cases) with saw chain SC-1 supplied by a renowned manufacturer and equipped with anti-kickback features (10 out of 15 cases) were characterized by the highest operating safety.

The results of analyses evaluating the influence of wood species, saw chain type and engine speed on the kickback angle are presented in Tables 3÷5. Engine speed had the smallest impact on the analyzed parameter, but it exerted a significant influence in interaction with other factors. Saw chain SC-1 ensured the highest level of operating safety, whereas saw chain SC-4 was characterized by the lowest safety despite the presence of anti-kickback features. These saw chains differed considerably in price, and the safer option was twice as expensive as its cheaper counterpart. The price accurately reflects the manufacturing precision and the quality of materials used in the compared saw chains. The potentially most unsafe wood was alder (average kickback angle of 38°), and the safest wood was spruce (average kickback angle of 21.41°). Pine, birch and oak were similar in this regard. The average kickback angle was also similar at the same engine speeds, and the greatest variations in the analyzed parameter were noted at 50% of maximum engine speed.

Table 3

The influence of wood species and engine rotational speed on the kickback angle

Type of saw chain	Kickback angle [°] $x \pm SD$	Probability p for:		
		1 – wood species	2 – engine speed	1 × 2
SC-1	21.65 ± 9.41	< 0.001	0.002	< 0.001
SC-2	26.49 ± 6.76	< 0.001	< 0.001	< 0.001
SC-3	33.86 ± 8.77	< 0.001	< 0.001	< 0.001
SC-4	36.07 ± 9.61	< 0.001	< 0.001	< 0.001

$x \pm SD$ – mean value ± standard deviation
The analyzed factor significantly influences the kickback angle at a probability level of $p < 0.05$.

Table 4

The influence of saw chain type and engine rotational speed on the kickback angle

Wood species	Kickback angle [°] $x \pm SD$	Probability p for:		
		1 – saw chain type	2 – engine speed	1 × 2
Pine	28.89 ± 10.70	< 0.001	< 0.001	< 0.001
Spruce	21.41 ± 6.35	< 0.001	< 0.001	< 0.001
Birch	29.18 ± 5.73	< 0.001	0.087	< 0.001
Alder	37.99 ± 6.40	< 0.001	0.167	< 0.001
Oak	30.13 ± 13.39	< 0.001	0.001	< 0.001

$x \pm SD$ – mean value ± standard deviation
The analyzed factor significantly influences the kickback angle at a probability level of $p < 0.05$.

Table 5

The influence of saw chain type and wood species on the kickback angle

Engine speed	Kickback angle [°] $x \pm$ SD	Probability p for factor:		
		1 – saw chain type	2 – wood species	1 × 2
n_{50}	29.28 ± 11.78	< 0.001	< 0.001	< 0.001
n_{75}	29.46 ± 10.75	< 0.001	< 0.001	< 0.001
n_{100}	29.82 ± 8.54	< 0.001	< 0.001	< 0.001

$x \pm$ SD – mean value ± standard deviation
The analyzed factor significantly influences the kickback angle at a probability level of $p < 0.05$.

Discussion

Chainsaw kickback is determined by both technical and operating factors (DĄBROWSKI 2012, 2015, WÓJCIK 2013). Technical factors include engine power, engine displacement, type and length of the guide bar, type of saw chain and efficiency of the cutting assembly. Operating factors are largely determined by the chainsaw operator who makes individual decisions regarding engine settings, the technical condition and tension of the saw chain, cutting technique and the use of protective equipment.

According to DĄBROWSKI (2012), operators should choose low-profile saw chains as well as saw chains with anti-kickback features. However, the results of this study revealed that drive links with a higher pitch do not always reduce kickback. Saw chain SC-4 was characterized by the largest average kickback angle which was even larger than in chain saws without anti-kickback features (SC-2 and SC-3). This suggests that kickback is significantly influenced by the profile of chain links, manufacturing precision and the quality of structural materials, which translates to a higher price. A comparison of the kickback angles of standard saw chains (SC-2 and SC-3) leads to similar conclusions (Tab. 3). Therefore, saw chains from renowned suppliers are more likely to guarantee manufacturing precision and operating safety.

Engine speed is controlled with the throttle trigger. According to DĄBROWSKI (2012), the kickback angle increases with an increase in the engine's rotational speed because the kinetic energy imparted to chain links is used mainly for wood cutting. When the saw chain remains in contact with wood for a relatively long time, most of the generated energy is dispersed in the cutting process, which reduces kickback. In this study, the kickback angle of chainsaws equipped with the tested saw chains was significantly influenced when the engine was operated at 50–100% of maximum power in the analyzed wood species (the absence of such influence was noted only in birch and alder, Tab. 4). However, the nature of the observed changes is difficult to describe due to interactions between the analyzed factors. The above observations are confirmed by the nearly equal average values of the kickback angle at the analyzed engine speeds (Tab. 5). Engine speed and, consequently, chain speed could exert a varied influence on the kickback angle due the presence of bark which is the first element that comes into contact with the saw chain. Bark surface is often uneven (due to the presence of cracks and groove), and the generated energy is dissipated differently on various types of wood.

According to DĄBROWSKI (2015), kickback is influenced by ambient temperature and the moisture content of wood. The kickback angle is largest at temperatures approximating 0°C and smallest when the processed wood is frozen. At low temperatures, wood fibers lose their elasticity, and their arrangement does not significantly influence the cutting process. In wood with high moisture content, fibers offer greater resistance against cutting teeth, which also increases kickback. The above implies that debarking of freshly cut trees requires greater caution than processing of declining trees or pre-dried wood. The wood samples analyzed in this study were characterized by high moisture content, therefore the noted kickback angles (Tab. 2) were close to the maximum values.

The kickback angle is also largely determined by wood species (Tab. 4). The smallest average kickback angle was noted in spruce, and the largest – in alder. Our findings do not fully conform to the observations made by DĄBROWSKI (2015) in whose study, kickback angle was not influenced by the hardness (and species) of wood. In the cited study, the largest kickback angle was reported in spruce, followed by oak and pine, and the smallest value of the analyzed parameter was noted in beech. The observed differences could be attributed to the fact that the samples analyzed in the cited study had been debarked. In the current study, trunk diameter was also an important factor (Tab. 2) which was smallest in spruce and largest in birch. According to DĄBROWSKI (2015), the kickback angle is proportional to the trunk's radius of curvature. In trunks with a larger radius, a longer section of the saw chain is wedged into the wood, which increases chain speed at the nose, transfers more energy in the opposite direction and causes kickback.

Conclusions

The results of this study indicate that chainsaw kickback is largely determined by wood species and saw chain type and is less influenced by engine speed. A clear pattern of changes in kickback angle is difficult to identify due to multiple interactions between the analyzed factors. In the present study, the kickback angle varied considerably from around 12° to around 55°. The average value of the analyzed parameter was smallest in spruce and highest in alder, whereas pine, birch and oak were characterized by similar kickback angles. Considerable differences in average kickback angle were also observed between the tested saw chains. Not all chains with anti-kickback features effectively reduced the analyzed parameter. The kickback angle was decreased when the chainsaw was equipped with higher-priced chains made of higher-quality materials and characterized by greater manufacturing precision. Higher-priced saw chains were safer to operate than their cheaper counterparts. Chainsaw buyers should decide whether it is worthwhile to compromise on safety in exchange for a low price.

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