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REMOVING SINGLE LIMBS USING A ROTARY AUGER CUTTER

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ABSTRACT.—An experiment using auger cutters to remove single limbs from six species showed that torque required depends on species and relative cutter rotation direction and that all species require 2 horsepower or less per inch width of cut using 2½-inch-diameter cutters.

KEY WORDS: Delimbing, experiment, milling cutters, torque, up-milling, down-milling.

Delimbing is one of the least mechanized aspects of tree harvesting. The proper design of mechanized delimbing equipment requires a knowledge of the forces and energy required to remove single limbs. One recent publication does address the use of a single stroke shear to remove limbs from eastern Canadian conifers (Johnston and St-Laurent 1974), but no published data are available on other methods or species. This report describes results from tests of auger cutters used to remove single branches from six important Lake States species.

DESCRIPTION OF ROTARY AUGER CUTTER

A rotary auger cutter (technically a peripheral milling cutter) resembles a drill but cuts on its side or periphery rather than its end (fig. 1). Cutters of this type, which are presently used on commercially produced feller/bunchers,make a smooth, clean cut with no splitting of the wood fibers and do not dull easily. An extensive study of auger cutters recommended optimum rake and helix angles of 30 degrees and 40 degrees, respectively, based on torque and horsepower values (Mattson 1980). For this study, a cutter 3 inches long was mounted on a conventional horizontal milling machine (fig. 2).

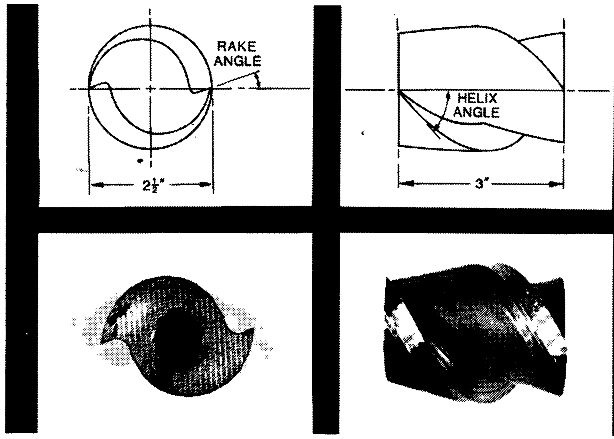

Figure 1.—*Geometry of rotary cutter.*

PROCEDURE

The samples tested were short tree sections, each with a single branch or limb as shown in (fig. 3). The samples were clamped to the movable workpiece table and fed toward the fixed rotating cutter using the automatic table feed. The cutter rotational speed was nominally 980 revolutions per minute (rpm), and the table feed speed was 13 inches per minute. Peripheral milling uses one of two distinct types of cutting action: up-milling or down-milling The difference between them is the direction of cutter rotation *relative* to the workpiece and its feed direction (fig. 4). Half the samples were cut using up-milling and the other half using down-milling.

In all cases the cutting began on the lower side of the branch (nearest the butt of the tree) and proceeded toward the top. A practical delimbing device would have multiple cutting heads; pulling trees through by

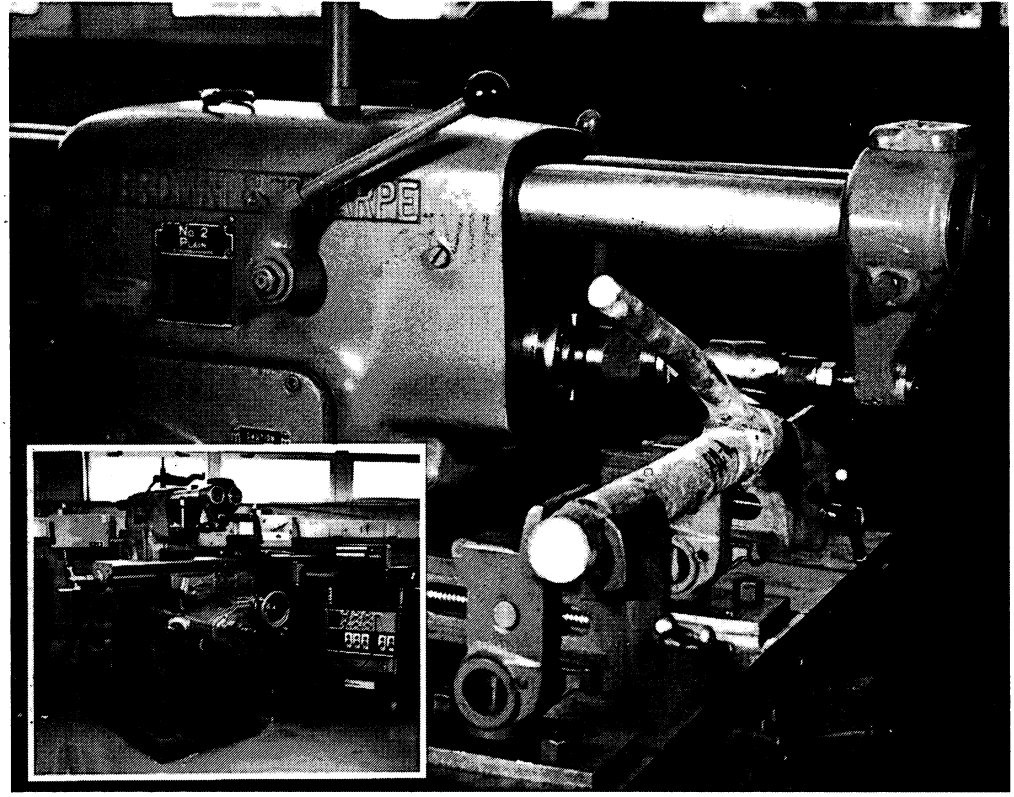

Figure 2.—*Equipment setup and instrumentation system for study.*

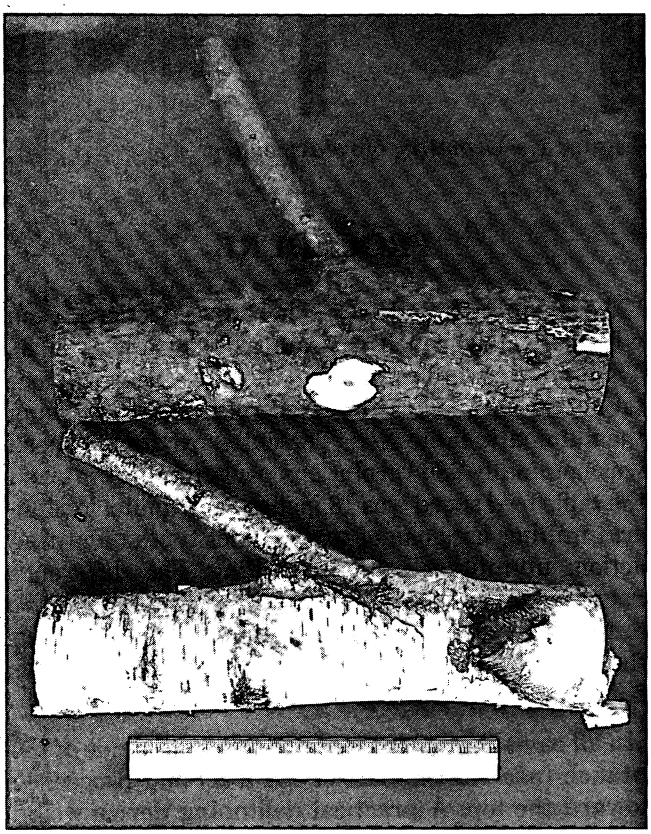

Figure 3.—*Typical single limb branch sample.*

their tops would cause the branches to jam against the framework of the delimber. Although the auger cutter is capable of cutting limbs in either direction, it would seem impractical to build a production delimbing device using auger cutters that worked from the tree top toward the butt.

The data recorded for each sample during cutting were cutter torque, time-integrated torque, cutter rotational speed, table feed speed, and relative cutter rotation direction. The torque signals were obtained from strain gages, the rotational speed from a magnetic pickup device, and table feed speed from a photo-optical sensor activated by a light shining through a comblike device. All signals were electronically amplified and then permanently recorded using an oscillograph.

The species tested were sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), quaking aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), balsam fir (*Abies balsamea*) and jack pine (*Pinus banksiana*). In addition to being predominant commercial species, they represent a range of specific gravities (nominal values 0.34 to 0.56) and branching characteristics. Sixteen samples of each species were tested with no more than four from the same tree. All samples were tested in the green or "as received" condition; none were frozen.

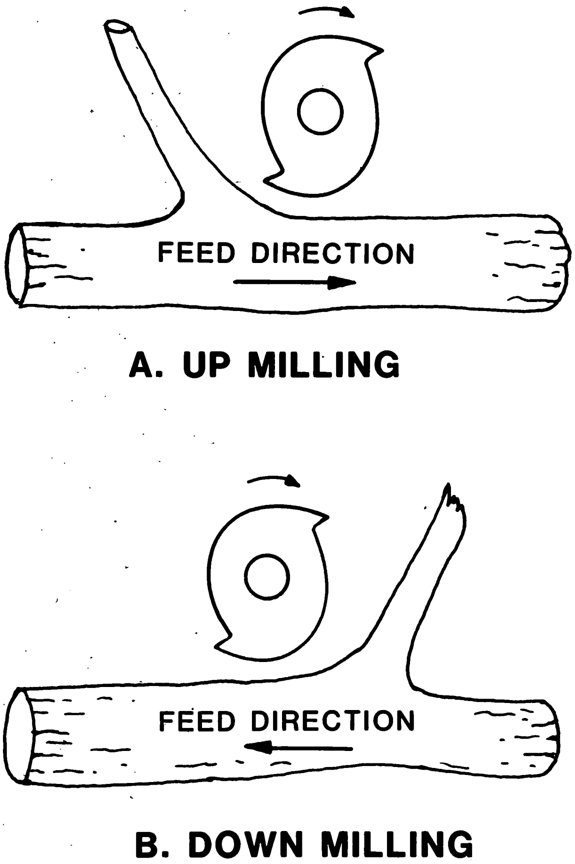

Figure 4.—*Schematic of relative cutter rotation directions.*

After the branches were severed from the main stem, a small disc was cut from both the branch and the main stem near their juncture for determination of percent moisture content and specific gravity. The disc from the main stem was cut directly below the branch juncture, and that from branch was cut approximately 1 inch away from the cut end of the severed branch. Moisture content was determined on a dry weight basis, and specific gravity on a dry weight-green volume basis as specified by TAPPI Standard T 18 M-53 (TAPPI 1967).

Four samples of each of the six species were tested in each of the two relative directions, giving 48 test runs. The entire experiment was then replicated, for a total of 96 test runs.

RESULTS

The mean physical properties of both the branch and stem fiber for all species are detailed in table 1. The green density of stem and branch samples for each species was similar. The percent moisture content of stem and branch samples was similar for jack pine, white birch, red maple, and sugar maple. In balsam fir and aspen, however, moisture content was higher in the stem than in the branches. The specific gravity for branch and stem portions was similar for all species except for balsam fir whose stem specific gravity was much lower than the branch.

The mean dimensional details of all samples are also shown in table 1. Note that the average acute angle between stem and branch is species-related, and that balsam fir had a much smaller average branch diameter than the other species.

The mean power requirements for cutting the branches are listed by species in table 2. The average torque was calculated by dividing the time-integrated torque by the time of the cut; mathematically this is expressed as:

$$T_{AVG} = \frac{\int_{t_1}^{t_2} T\,dt}{t_2 - t_1}$$

where:
T_{AVG} = average torque,
T = actual torque signal, and
t_1 , t_2 = time at beginning and end of cut, respectively.

The peak torque values are simply the maximum values obtained regardless of duration. Both the average and peak torque values are important in designing a machine to remove branches using auger cutters; the average torque or horsepower is a continuous power requirement, while the peak values indicate short-duration, maximum-power requirements. Note that the torque and horsepower values (both maximum and average) were normalized to a "per inch width of cut" basis by dividing them by the branch diameter.

After examining scatter plots of the various parameters, a two-way analysis of variance was made to determine the dependence of torque on species and relative cutter rotation direction (table 3). It describes the dependence (based on an F test) of peak torque, peak torque per inch width of cut, average torque, and average torque per inch width of cut on species and relative cutter rotation direction. As seen in table 3, the dependence of all torque values on species was significant at the 99-percent level. On the other hand, average torque was not even remotely dependent on relative cutter rotation direction, while both the peak torque and normalized peak torque were dependent at the 95-percent level. In addition to being highly dependent on relative cutter rotation direction, the

Table 1. — *Mean physical and dimensional properties of test of six Lake States species*

	Balsam fir	Jack pine	Aspen	White birch	Red maple	Sugar maple
Green density (lbs/ft³)						
Stem	58.0(4.7)[1]	60.2(3.0)	52.3(2.2)	59.8(1.0)	57.1(3.4)	62.0(2.0)
Branch	57.6(6.2)	60.8(4.0)	47.2(2.4)	59.4(2.9)	52.9(3.7)	58.1(3.7)
Moisture content (%) (Dry basis)						
Stem	126.9(11.4)	131.3(15.3)	84.3(9.6)	81.6(6.2)	62.8(7.5)	63.0(4.9)
Branch	79.9(14.9)	127.3(25.9)	66.8(.92)	86.1(6.9)	57.7(10.7)	58.3(9.5)
Specific gravity (Green basis)						
Stem	.41(.03)	.42(.03)	.46(.02)	.53(.01)	.56(.04)	.61(.03)
Branch	.51(.05)	.43(.04)	.45(.03)	.51(.02)	.54(.02)	.59(.03)
Stem diameter (inches)	3.7(.43)	3.5(.57)	3.1(.86)	2.8(1.03)	3.1(.68)	3.1(1.02)
Branch diameter (inches)	.76(.14)	1.1(.24)	1.6(.43)	1.4(.53)	1.4(.57)	1.4(.32)
Angle - branch to main stem (degrees)	64.1(14.2)	44.4(15.7)	54.4(19.0)	26.9(10.3)	28.1(10.7)	32.1(7.8)

[1]*Numbers in parenthesis are standard deviations.*

Table 2. — *(Mean power requirements by species)*

	Balsam fir	Jack pine	Aspen	White birch	Red maple	Sugar maple
Average torque (lbs)	5.8(3.3)[1]	10.1(3.9)	17.0(3.8)	18.1(10.9)	19.3(11.1)	24.9(10.2)
Average horsepower (hp)	.09	.16	.27	.29	.31	.40
Peak torque (lbs)	66.8(19.9)	105.7(44.3)	157.3(70.1)	149.6(72.2)	184.0(124.6)	181.7(53.6)
Peak horsepower (hp)	1.1	1.7	2.5	2.4	2.9	2.7
Average torque (Normalized) (lbs/inch width of cut)	7.6(4.2)	9.1(2.7)	10.1(3.3)	11.8(3.8)	13.5(3.6)	17.8(4.3)
Average horsepower (Normalized) (hp/inch width of cut)	.12	.14	.16	.19	.22	.29
Peak torque (Normalized) (lbs/inch width of cut)	89.0(26.3)	94.2(29.0)	96.0(26.3)	100.9(23.6)	122.2(31.6)	138.7(29.4)
Peak Horsepower (Normalized) (hp/inch width of cut)	1.5	1.5	1.5	1.6	1.9	2.1

[1]*Numbers in parenthesis are standard deviations.*

Table 3. — *F values for two-way Anova (95 df) on species and cutter rotation*

	Species (5 df)	Cutter rotation direction (1 df)
Peak torque	6.69[1]	5.15[2]
Peak torque/ inch width of cut	6.29[1]	10.65[1]
Average torque	10.74[1]	1.42
Average torque/ inch width of cut	14.63[1]	.70

[1]*Significant* $p < 0.01$.
[2]*Significant* $p < 0.05$.

magnitude of peak torque was always lower with up-milling. The mean normalized peak torque for all species combined was 112.9 in-lb/inch width of cut for relative up-milling and 143.2 in-lb/inch width of cut for down-milling.

CONCLUSIONS

A mechanical delimber using auger cutters would have the advantage of clean, smooth cuts with little or no branch stub remaining. The cutters are rugged, efficient, self-cleaning, and easily sharpened. The horsepower requirements of auger cutters for cutting branch-size material are low enough to allow the use of hydraulic motors. In addition, using the auger in an up-milling orientation requires less power. The data provided here, expecially for hardwoods, should provide a starting point to aid in the design of new mechanical delimbers.

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