FERIC *FOREST ENGINEERING RESEARCH INSTITUTE OF CANADA*
INSTITUT CANADIEN DE RECHERCHES EN GÉNIE FORESTIER

Technical Report No. TR-56

March 1984

Circular Saw and Cone Saw Felling Heads: An Update

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Ce rapport technique est disponible en français

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PREFACE

This report provides up-to-date information on the production and mechanical characteristics of four circular saw and one cone-saw felling head. All of these units are new to the Canadian logging industry. The length of operating experience with each type varies considerably. For this reason one can reasonably assume that further improvements will yet be made to several of these felling heads.

FERIC's earlier role in the development of the Koehring and Harricana circular saw heads (see Technical Note TN-58) does not prevent it from carrying out an objective assessment of competing felling heads. Although both Koehring and Harricana's felling heads use principles covered in a FERIC patent application they pay no royalty to FERIC. The other three manufacturers each have individual patent protection for their felling heads while Koehring also have a patent application covering features of their design.

This report required the co-operation of many individuals and companies. We would like to acknowledge the manufacturers of the circular saw and cone felling heads and the forest industries that used them. Their assistance and co-operation was essential to this project:

Abitibi-Price Inc., Iroquois Falls, Ont.
Clouthier Bros. Ltd., Strickland, Ont.
Dubreuil Bros. Ltd., Dubreuilville, Ont.
Équipement Hydraulique Boréal, Macamic, Qué.
Great Northern Paper Co., Millinocket, Maine
Harricana Métal Inc., Amos, Qué.
Koehring Canada Ltd., Brantford, Ont.
Les Équipement Denis Inc., Ste-Rosalie, Qué.
Matériaux Blanchette Ltée, Amos, Qué.
Rauma-Repola Int. Ltée, Pointe Claire, Qué.
United Sawmill Ltd., Hearst, Ont.

The contributions of FERIC employees P.G. Mellgren (engineering assistance) M. St-Amour and J. Courteau (technical assistance) was also greatly appreciated.

A metric conversion table is provided in Appendix H, at the end of this report.

M.P. Folkema is a graduate of Lakehead University and a registered member of the Ont. Prof. For. Assoc.

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SUMMARY

This Technical Report is intended as a follow-up to FERIC's Technical Note TN-58 "Using Circular Saw Felling Heads to Reduce Butt Splitting Damage", which was published in May, 1982. The earlier publication described the development of the Harricana and Koehring prototype saw heads. This Technical Report summarizes the results of FERIC studies of three circular saw heads that are now considered to be "production" units; the Koehring and Harricana and the Denis (which uses two circular saws). Also in this report are the study results of the Boreal (double deck) and Lokomo (cone saw) heads, both of which are classified as "pre-production" units.

Development activity among the manufacturers of these "non-shear" felling heads has been at a high level during the past two years. This occurred despite the economic recession in the forest industry. During this two-year period several of the heads have been completely re-designed to increase their reliability and productivity. Prospective buyers should be careful not base their assessments on their experience with earlier versions because the new versions may be very different.

FERIC's studies indicate that several of the "non-shear" felling heads can now be considered operationally reliable. They also significantly reduce butt splitting damage, particularly in frozen wood conditions. For these reasons, it is likely that, because of company or government policy, shears will not be permitted on many logging operations producing sawlog products in the near future. This is already the case in the B.C. Interior where some sawmills refuse to accept sheared wood.

FERIC recommends that a side-tilt (wrist) feature be mandatory for all five "non-shear" heads for nearly all carriers. If no side-tilt feature is provided, even carriers providing 2-way tilt on the turntable (e.g. Drott 40), can cause significant butt splitting, especially when harvesting on slopes beside the machine. Even on flat ground, an operator can easily place a bending moment on an angled tree, which will cause butt splitting damage. The Timbco 2518 carrier, with its 4-way tilt may not require a side-tilt feature.

The choice of which "non-shear" felling head to purchase depends on many factors, all of which must be taken into consideration. Examples are: the availability of a suitable carrier, hydraulic flow and cooling capacity, tree size, the presence of rocky terrain, operator skills and attitude, etc. A "non-shear" felling head that works well in one area may not be the best choice for another area having different conditions. The reader is particularly advised to study the Conclusions section of this report where a comparison of the five "non-shear" felling heads is provided in tabular format.

INTRODUCTION

In May 1982, FERIC released Technical Note TN-58 "Using Circular Saw Felling Heads to Reduce Butt Splitting Damage and Increase Productivity". TN-58 provided the background behind FERIC's circular saw head project and described the development and early test results with the Harricana and Koehring prototypes. It also outlined the degree of success that was achieved in eliminating butt splitting damage caused by the use of shears.

Although these early results were encouraging, the units described were "prototypes". Modifications to both the Koehring and Harricana heads were required. This report is partly intended as a supplement to TN-58 since it provides shift-level information on these two felling heads which can now be regarded as "production" units.

Several other new "non-shear" felling heads are also discussed in this report. Two of these, the Denis "twin saw" and Boreal "double-deck" saw appear to have been inspired by the earlier single circular saw types. The Lokomo cone saw, which was developed in Finland, is also discussed.

The object of this report is to provide useful information for a prospective user or buyer. Each section has been reviewed by its respective manufacturer and user company. The summary and conclusions are by FERIC and may not necessarily reflect the views of the manufacturers or current machine users.

KOEHRING DISC SAW

Koehring Canada Ltd. built its first "disc" felling head in June 1981 as the result of an earlier proposal by FERIC. Patent protection for the Koehring disc saw is provided by a 1981 patent application (358,817) by FERIC. Manufacturing rights deriving from FERIC's patent application, especially the "sever before grasp" feature, have been granted to Koehring Canada and Harricana Métal without payment of royalties. FERIC is prepared to negotiate the use of their patent concepts with other manufacturers. Both Koehring Canada and Harricana Métal have invested considerable time, effort and money to develop their respective circular saw felling heads. The development and testing of the first Koehring prototype units is outlined in FERIC's Technical Note TN-58 [1]. Additional information is provided in recent reports by Marshall [2] and Bjerkelund [3].

The new Koehring disc saw head (see Appendix B) weighs 2360 kg, a considerable weight reduction from the earlier prototype versions. It now includes a side-tilt feature and a boom adaptor. The disc head is available in only one size (50-cm capacity) and costs $52 200 not including installation. Koehring Canada supplies the disc head on any new or used carrier that meets the minimum requirements. It is recommended that excavator-type carriers have a minimum weight of 22 700 kg (50,000 lb) with 100 kW (135 Hp) net engine power. A discussion of hydraulic requirements is provided on p. 16.

The new Koehring disc head is different from all other circular saw or cone heads (described in this report) because it can cut with a "scything" technique as well as with a "frontal" method.

This report includes FERIC studies of two Koehring disc heads on feller forwarders. The production of feller forwarders is, of course, much lower than for feller bunchers. The disc head used on a KFF at Dubreuilville, Ontario during 1982 was one of the prototype designs which was much heavier than the new version. The experience with this and several similar heads (on feller bunchers) permitted Koehring to re-design their disc head. The second FERIC study is of the first re-designed head (similar to the version available now) built and tested by Koehring. It was mounted on a Koehring K2FF feller forwarder operated (and later owned) by Great Northern Paper Co. Ltd. near Portage, Maine.

Koehring Canada have had a lengthy and rather costly program to develop their new disc saw head. Recently, however this investment has resulted in felling head sales, mainly in B.C. By the end of Nov. 1983, twelve of the newly designed heads were sold/operating in B.C. They were mounted on a variety of excavator-type carriers, including the Cat 225, 227 and 235, the Koehring 266 and the Hitachi UH121. Additional units are now in use in several other parts of Canada and in the U.S.

DUBREUIL BROS. LTD., DUBREUILVILLE, ONT.

The Koehring prototype disc saw, a converted shear-type head with a 45^{o} adaptor, was mounted on a Koehring feller forwarder (Model KFF). The disc saw head was tested here because butt shatter was a significant problem for the company's sawmill; also the Koehring shear head (on a second KFF) suffered from high downtime and repair costs mainly because of the large tree size (mostly large jackpine), rough terrain and the large amount of rocks and boulders. The terrain classification here was mostly 1.3.3 [4].

FERIC data on the disc saw was collected during 4-months in the first half of 1982. This period was also used by Koehring Canada to test various types of saw blades under adverse conditions. Eight different saw blades were tested and replaced at Koehring's expense (see Fig. 1). In late June 1982, the disc felling head was replaced with a shear. In Dec. 1982, the same disc felling head was installed on the KFF, using the successful saw design developed at Great Northern Paper. Although no data were collected by FERIC from this second trial, it was reported that saw blade damage from rocks was again the main problem and because of this the results were not satisfactory.

During FERIC's 4-month study, the KFF disc saw operated in two areas about 30 km from Dubreuilville, on a variety of terrain ranging from flat ground to boulder-strewn slopes and gullies with slopes of 20% or more. The roughest terrain was usually harvested with manual felling and skidders. The snow depth was 1.2 m or more during FERIC's study, thus making it difficult for the operator to see boulders under the snow. The operators were hourly paid with no bonus provision and worked on a 2-shift-per-day basis, 5 days per week.

Production: The average productivity during FERIC's 4-month study was 60 trees (felled and forwarded) per PMH, or 12.7 m^3 per PMH, based on an average tree size of .213 m^3. A Dubreuil Bros. supervisor told FERIC that there was no discernible difference between the productivity of their KFF with shears as compared to the KFF with the disc saw for the reasons discussed below. The two machines were operated together.

The disc saw felling design presented several problems or limitations. NOTE: Most of these limitations (listed below) were corrected on the newly-designed version of the disc head.

1. When using the "scything" principle (swinging the boom sideways) the maximum tree size that could be cut was limited to 20 cm (see Fig. 1).

   To cut trees over 20 cm (stump diameter), the operator had to operate not only the swing but also the main boom and stick boom controls. This permitted the saw pocket to be moved in a forward and sideways arc permitting trees up to 50 cm to be felled and bunched. For trees over 20 cm, the operator usually positioned the head directly beside the tree before beginning the cut sequence. The technique was more difficult to learn as compared to that for the shear head. It contributed to high torque forces on the saw blade and saw blade failure.

Table 1. Shift Level Study Results: Koehring Disc Saw on Koehring Feller Forwarder Model KFF at Dubreuil Bros. Ltd., Dubreuilville, Ont.

		March 1982	April	May	to June 24, 1982	Total
Scheduling						
Days Reported	(DY)	22	21	18.0	14	75
Scheduled Time	(HR)	374.0	330.5	320.5	238.0	1263.0
Out-of-Shift Time	(HR)	-	9.5	8.0	7.0	24.5
Total Time	(HR)	374.0	340.0	328.5	245.0	1287.5
Shifts/Day	(SH/DY)	2	2	2	2	2
Machine						
Repair In-Shift	(HR)	88.5	93.5	38.5	51.5	272.0
Repair Out-of-Shift	(HR)	-	-	1.5	2.5	4.0
Service In-Shift	(HR)	18.5	12.0	10.5	4.0	45.0
Service Out-of-Shift	(HR)	-	1.5	1.0	-	2.5
Operations						
Non-Prod. Operating Time	(HR)	11.5	8.0	25.5	9.0	54.0
Wait Parts	(HR)	-	-	-	-	-
Wait Mechanic	(HR)	26.0	12.0	6.5	-	44.5
Miscellaneous Delays	(HR)	22.0	15.0	8.0	3.0	48.0
Machine and Operations						
PMH In-Shift	(HR)	207.5	190.0	231.5	170.5	799.5
PMH Out-of-Shift	(HR)	-	8.0	5.5	4.5	18.0
CPPA Availability	(%)	64	64	83	77	75
Mechanical Availability	(%)	66	67	82	75	72
Utilization	(%)	55	57	73	72	63
Total Time Utilization	(%)	55	58	72	72	63
Production						
Total Production	(m^3 (ct))	2377 (839)	2067 (730)	2877 (1016)	2879 (1017)	10200 (3602)
Trees Harvested	(TR)	12,502	10,871	13,149	11,286	47,808
Volume per Tree	(m^3 (ft^3))	.189 (6.7)	.190 (6.7)	.219 (7.7)	.255 (11.1)	.213 (7.5)
Trees per PMH	(TR/PMH)	60	57	57	65	60
Productivity	(m^3/PMH (ct/PMH))	11.4 (4.0)	10.4 (3.7)	12.1 (4.3)	16.5 (5.8)	12.7 (4.5)

Table 2. Repair Summary: Koehring Disc Saw on Koehring Feller Forwarder Model KFF at Dubreuil Bros., Dubreuilville, Ont.

	Repair Time (hrs)					Comments
	March 1982	April	May	to June 24 1982	Total	
FELLING HEAD REPAIRS						
Structural						
Main frame or post						
Adaptor (between boom and felling head)						
Tree support (T-shaped)						
Pins & bushings						
Grab arms - upper						
- lower						
Protective saw cover	1.0				1.0	
Disc saw assembly - shaft & bearings						
- Repair/Sharpen	4.0	74.0		3.5	81.5	- welding on saw - a single repair (74 hr) in April - no detail provided
- Replace	6.0	3.5	4.0	3.0	16.5	- 8 different saw designs were tested for Koehring Canada
- Butt plate		2.5			2.5	- weld butt plate
Other (weld on plates)	25.5		1.0		26.5	- weld plates on head, March
Hydraulic						
Disc saw motor	3.0		2.5		5.5	- clean motor, May
Flexible hoses		3.5	3.5	21.0	28.0	- tighten/replace hoses (11 x) in June
Fittings	1.5			2.5	4.0	- tighten/replace fittings
Cylinders - upper grab arm						
- lower grab arm						
Other				12.5	12.5	- repair tilt cylinder (3 x)
SUB TOTAL	41.0	83.5	11.0	42.5	178.0	
CARRIER REPAIRS						
Power and transmission unit	4.5	6.5	.5		11.5	- no detail provided - problem with motor, April
Drive system (incl. tracks or wheels)	6.0		11.5	9.0	26.5	- mostly repairs to differential, May & June
Hydraulics on boom (only)	5.5				5.5	- no detail provided
Hydraulics (general)	9.5		2.5	2.0	14.0	- repair hydraulic pump, March
Electrical system	6.5			.5	7.0	- no detail provided
Chassis and frame		1.5			1.5	
Booms					-	
Swing assembly	13.5	2.0			15.5	- repaired broken chain swing on boom, March & Apr.
Engine overheating	2.0		14.5		16.5	- includes wash engine & machine (6 hr), May
SUB TOTAL	47.5	10.0	29.5	11.5	98.0	
TOTAL	88.5	93.5	40.0	54.0	276.0	

2. The operator also had to grab the tree within 1 or 2 seconds after it was felled. If the saw head was not well aligned with the tree, part of the saw head could touch the tree before it was grabbed, thereby pushing it in the wrong direction before the grab arms could close, with the result that the tree would "jackstraw" (be held crooked). Also if a tree had a pronounced lean, it was difficult for the operator to grab the tree effectively after severing it. Poorly held ("jackstrawed") trees in the saw felling head were common on the Dubreuilville KFF.

3. Dropped trees were more difficult to pick up with the saw head, as compared to shears. As the saw head was tilted forward to pick up a fallen or dropped tree, the saw could hit the ground, with possible saw blade damage resulting. If the operator stopped the saw, productive time would be lost waiting for it to stop and later to build up RPM again. Visibility with the tilted saw head was also reduced, as compared to shears, making it awkward to pick up dropped trees.

4. Although the KFF supplied sufficient hydraulic flow and pressure for the circular saw most of the time, it was noted that on larger trees the operator often had to wait several seconds for the saw to build up to normal R.P.M. (1200) between trees.

5. On the KFF, the left grab arm interfered with down piling of full trees onto the bunk. The trees tended to strike the grab arm causing them to fall crooked on the bunk. It required extra time for the operator to straighten out these trees.

Repairs: During FERIC's 4-month study 64% of the total repair hours were on the Koehring disc head and 36% were on the KFF carrier. Most of the repair downtime with the disc head was caused by saw blade damage from rocks.

Saw Blades: The terrain at Dubreuilville was unfavourable for the disc saw because of the boulder-strewn terrain and because 1.2 m of snow covered these boulders. The disc head used here was one of the first built by Koehring. Most of the saw blade designs built by Koehring were tested here during the same period and on the same KFF studied by FERIC. Most of Koehring's early blade designs were expensive, multi-piece (refers to the blade itself not the teeth) designs ranging in cost up to $6000 each (NOTE - the current (Oct. 1983) standard blade now costs $2400). Koehring used 8 different designs during the 4-month period. Some lasted only a few hours before requiring replacement/repair. Others lasted one month, or more. None were suitable. The tests, however, enabled Koehring to design a saw blade that has proved suitable for most rock-free or relatively rock-free conditions (see Fig. 2).

The multi-piece blades (see Fig. 1) usually failed because of metal stress (cracks) that appeared near the outside of the blade where the metal was welded. Sometimes stress was observed near the inside of the saw, also on a weld line (see Fig. 1). As explained in point 1 (Production), the upward scooping action when cutting larger trees using the boom swing, main boom and stick boom controls simultaneously caused unwanted torque on the saw blade as it was cutting through the tree (NOTE - on the new design (see Fig. 2) the saw opening is much larger, permitting a "scything" technique using only the boom swing control to be used for all sizes of trees up to 50 cm).

Damage to the saw teeth from rocks and boulders proved to be an even greater problem than metal stress because:

i) The teeth became dull and bent from hitting rocks.

ii) The downward-pointing edges of the lower set of teeth were bent upward, resulting in a friction surface rather than a cutting edge. Usually the thicker the teeth on the lower section the longer the saw would last in rocky ground.

The new type of Koehring saw blade, which has a 1-piece blade plus 9 teeth above and 9 teeth below (see Fig. 2) has been used successfully at Portage, Maine but not in the rocky terrain at Dubreuilville. Mr. P.G. Mellgren, P. Eng. of FERIC has proposed a new rugged "bolt-on" tooth design to overcome the problems associated with removing an entire saw blade and replacing another, especially if only 1 or 2 teeth are damaged. Instead of a repair job that requires up to 2 hours it should be possible to replace the damaged tooth (teeth) in 10 minutes using a torque wrench. The damaged tooth (teeth) can be re-ground in the shop and later re-used. FERIC has encouraged Koehring to carry out testing on this or other concepts in 1984. If successful, it should permit the use of the Koehring disc saw even on rocky terrain.

GREAT NORTHERN PAPER, PORTAGE, MAINE

Following the disc head testing at Dubreuilville, Koehring re-designed the entire head. The weight of the re-designed head was reduced nearly 700 kg to 2360 kg, operator visibility was improved and the saw pocket was re-designed to permit either "scything" of trees up to 50 cm, or "frontal" cutting. The new saw blade design having 18 welded-on teeth (9 above, 9 below) was also tested; this design has since become the "standard" blade supplied by Koehring Canada (see Fig. 2).

The new felling head was mounted on Koehring's (prototype) K2FF feller forwarder. The K2FF was tested and evaluated at Great Northern Paper Co. in a normal production situation. The K2FF's hydraulic system was well suited to the disc felling head; it had a "power beyond" feature and series connections for less circuit interference, resulting in a better, smoother felling cycle. The three pumps on the K2FF permitted selection of correct and independent oil flows for several functions (important for circular saw drive).

At Great Northern Paper, the K2FF operated in softwood stands that had been selectively cut (to a diameter limit) 15 years earlier. Thus, most of the remaining stands consisted of scattered spruce and fir that contained only 40 to 90 m^3 merchantable volume per hectare. Some patches containing a higher volume per hectare were scattered throughout the harvest area. The terrain in the harvesting area was rolling with long cutting faces and with only a few areas having gradients over 20^{o}. The terrain classification was mostly 2.1.2 [4]. There were virtually no boulders or protruding rocks. Spruce budworm damage was severe; between 15 to 50% of the trees were dead. Most of these dead trees were harvested since the fibre was still useable.

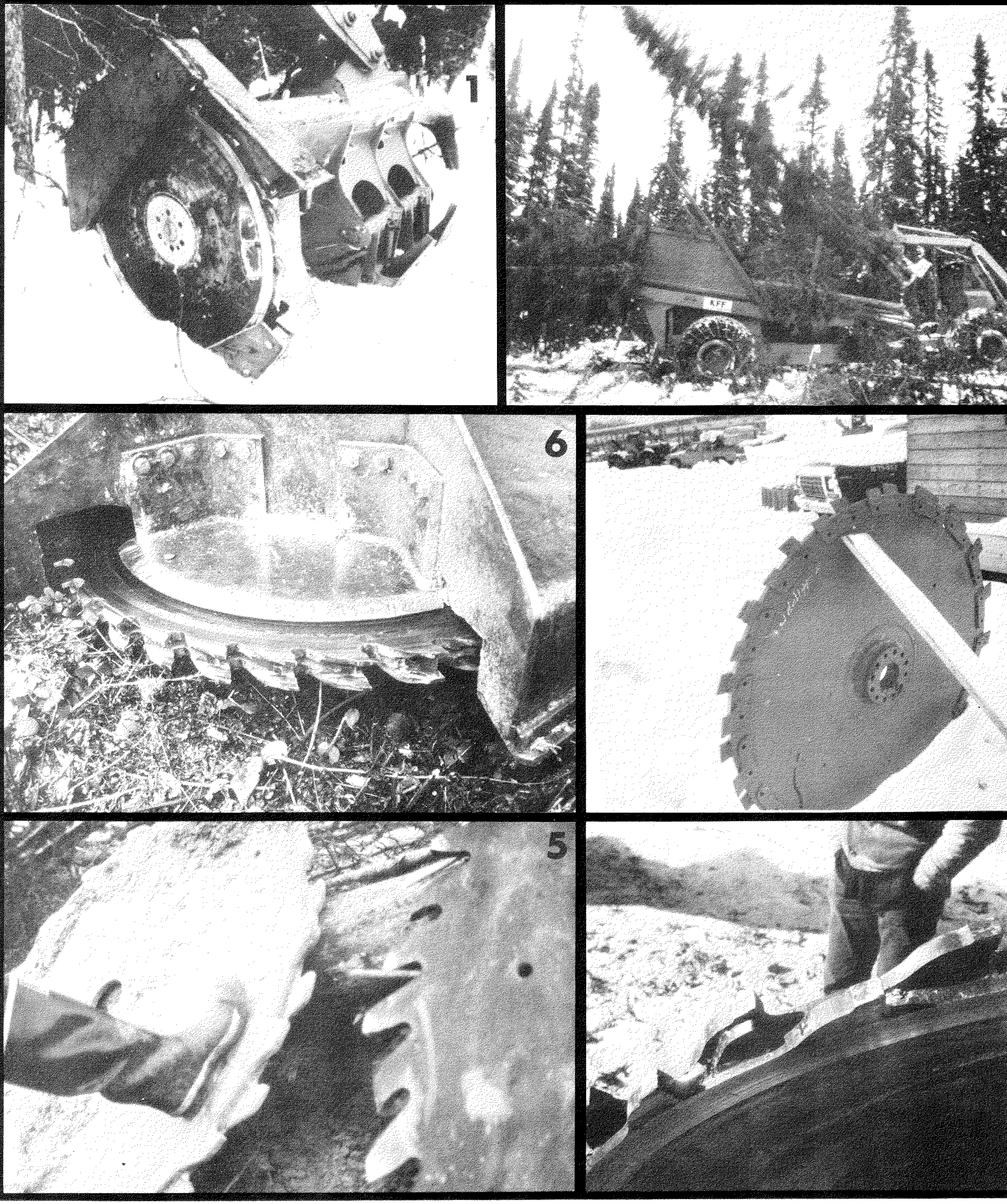

Fig. 1. Koehring disc saw head on Koehring feller forwarder Model KFF at Dubreuilville, Ont. 1982. This operation served as a testing area for Koehring - to test various disc blade desi Rocks proved to be a major limiting factor for the disc saw head here. 1: oblique view of di head showing weld patches; 2: KFF placing felled trees into the bunk; 3: one piece blade wi welded teeth - this design worked reasonably well; 4 and 6: expensive, multi-piece blades of different designs; 5: right, single-piece bent tooth blade, left, multi-piece blade.

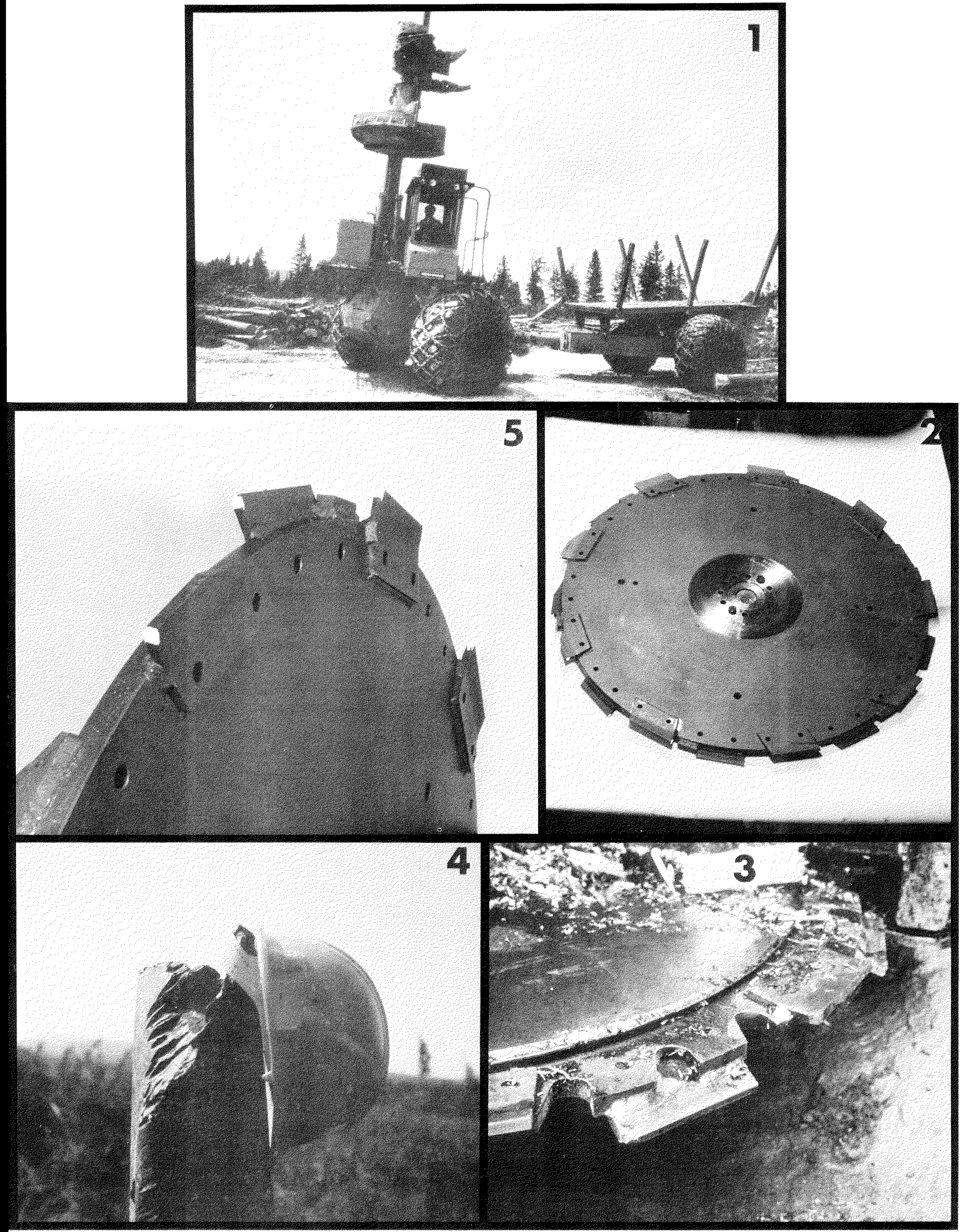

Fig. 2. New design Koehring disc head on K2FF feller forwarder at G.N.P., Portage, Maine. The disc head has been in regular use here for more than 10 months with very good results. 1: K2FF with disc saw head; 2 & 5: 'standard' 55-cm Koehring disc blade. It has 9 teeth above and 9 teeth below. Note carbide tips and centre rakers between the teeth for removing cut wood fibre; 3: close-up of disc blade on K2FF. The gullets used on the version was not used on latter versions; 4: front bunk post on K2FF - accidentaly cut by the disc saw.

Fig. 3. The Koehring disc saw (similar to the Harricana and Lokomo units) normally produces a rough, frayed surface. This may cause difficulty in determini the extent of butt rot for buckir or scaling purposes. The log in the centre has been freshly cut with a chain saw.

Fig. 4. Butt damage studies of trees felled by the K2FF's disc head were made using the "Bicycl Wheel" method. It showed that th rough, frayed surface (see Fig. was superficial. On most trees there was no evidence of butt splitting or other damage. Even trees with extensive butt rot, such as the one shown to the lef were undamaged. If this tree ha been cut with a shear the butt section would probably have been crushed. (See Appendix A for the study results.)

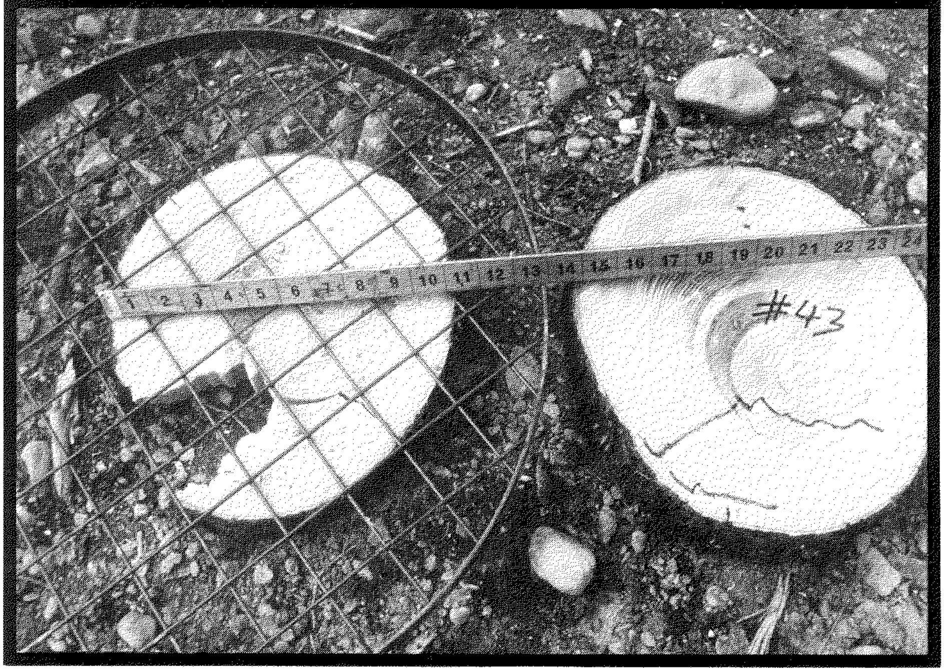

Fig. 5. Butt damage with the di head seldom occurs because the tree is grabbed after it is fully severed. However, butt damage ca occur (as on #43, right) if a tr is leaning towards the machine a is pushed by the top part of the head while it is being severed (see also Fig. 11).

Cull softwoods plus hardwoods (considered non-merchantable) comprised about 20 to 30% of the trees in the harvested areas. These trees were usually pushed over or severed with the disc saw head. Under normal conditions the machine forwarded up to 330 m, but occasionally it forwarded up to 600 m depending on road access.

The K2FF with its disc saw head was operated on a 2-shift basis, 4 days per week (80 SMH/wk). The operators were paid an hourly rate with no bonus provision. Both operators were considered experienced and capable; one new operator was trained during FERIC's 9-month study.

Production: The average productivity during FERIC's 9-month study was 71 trees (felled and forwarded) per PMH, or 15.1 m^3 per PMH, based on an average tree size of .213 m^3. This was done in low density stands with longer-than-average forwarding distances. Great Northern Paper also operated several shear-equipped Koehring feller forwarders (Model KFF). The felling and bunching of trees could be done more quickly with the disc head (as compared to the shear) because the disc head could be swung directly onto the tree and because the cut was faster (less than 1 second). Since the K2FF cab swings with the boom, operator visibility was better than on the KFF at Dubreuilville. Also, the 360° continuous swing on the K2FF allowed the operator to swing the shortest route to and from the bunk. The hydraulic system on the K2FF worked well for the disc saw; there was no waiting time for the saw to build up to normal RPM because of hydraulic flow required by other functions. Snow depth of .8 m from Jan. to March 1983 did not appear to have any effect on disc head productivity.

The saw pocket design on the K2FF's disc saw (see Fig. 2) permitted trees to be severed by extending the boom directly forward or by using a "scything" (side to side) motion of the turntable. The "scything" action could function twice as fast as the forward boom action with an experienced operator in normal stands [5]. NOTE - This new head design also overcame a potential problem caused by the old disc head design for feller bunchers. With the old type, after cutting a strip or pass with the 45° offset head, the machine had to dead-walk back to the start, unless it was circling the stand [6]. With the new design it can cut trees by extending the boom as well as by "scything" on one side, permitting it to cut effectively on the return trip.

Repairs: The disc head averaged less than 6 repair hours per month during FERIC's 9-month study, which was considered excellent; it represented only 18% of the total repairs on the K2FF. The good performance was attributed to the improved design of the saw head and blade, the suitable hydraulic system on the K2FF and the relatively rock-free terrain in the harvest area.

Some comments can be made:

1. The bottom cover of the disc saw was pushed upward several times causing the blade to hit the cover. This problem has since been rectified by Koehring by using stronger gussetting.

Table 3. Shift Level Study Results: Koehring Disc Saw on K2FF at Great Northern Paper Co., Portage, Maine.

		Dec. 1982	Jan. 1983	Feb.	Mar.	Apr.	May	June	July	Aug. 1983	Total
Scheduling											
Days Reported (4 da/wk)	(DY)	17	17	15	15	11[1]	12	18	12[1]	19	136
Scheduled Time	(HR)	330.0	341.0	230.0	173.0	223.0	234.0	358.0	200.0	383.0	2472.0
Out-of-Shift Time	(HR)	-	-	-	-	-	-	-	-	-	-
Total Time	(HR)	330.0	341.0	230.0	173.0	223.0	234.0	358.0	200.0	383.0	2472.0
Shifts/Day	(SH/DY)	2	2	1.6	1.2	2	1.9	2	1.6	2	-
Machine											
Repair In-Shift	(HR)	28.0	64.5	26.5	22.0	18.0	24.5	44.0	9.0	23.0	259.5
Repair Out-of-Shift	(HR)	-	-	-	-	-	-	-	-	-	-
Service In-Shift	(HR)	37.5	39.5	27.5	21.0	28.5	31.0	40.5	24.5	83.5	333.5
Service Out-of-Shift	(HR)	-	-	-	-	-	-	-	-		
Operations											
Non-Prod. Operating Time	(HR)	10.5	15.0	2.0	1.0	6.5	5.5	12.0	1.5	1.0	55.0
Wait Parts	(HR)	12.5	26.5	1.5	-	-	-	-	9.5	68.0[4]	118.0
Wait Mechanic	(HR)	11.5	10.0	7.0	-	-	-	1.5	3.0	3.0	36.0
Miscellaneous Delays	(HR)	28.0	27.0	21.0	16.5	8.0	9.0	20.0	12.0	3.5	145.0
Machine and Operations											
PMH In-Shift	(HR)	202.0	158.5	144.5	112.5	162.0	164.0	240.0	140.5	201.0	1525.0
PMH Out-of-Shift	(HR)	-	-	-	-	-	-	-	-	-	-
CPPA Availability	(%)	73	59	73	75	79	76	76	77	54	70
Mechanical Availability	(%)	76	60	73	72	78	75	74	81	65	72
Utilization	(%)	61	46	63	65	73	70	67	70	52	62
Total Time Utilization	(%)	61	46	63	65	73	70	67	70	52	62
Production											
Total Production	(m^3)	2471	2143	1976	1561	2247	1355	4568	2864	3871	23,056
Trees Felled & Forwarded	(TR)	13,094	12,237	10,452	8,258	11,888	5,789	19,505	11,340	15,485	108,048
Volume per Tree	(m^3)	.189	.175	.189	.169	.169	.234	.234	.253	.250	.213
Trees per PMH	(TR/PMH)	65	77	72	73	73	35[3]	81	81	77	71
Productivity	(m^3/PMH)	12.2	13.5	13.7	13.9	13.9	8.3[3]	19.0	20.4	19.3	15.1

[1] Operators on vacation (1 week).

[2] Periodic 500 hr service (with Koehring Ltd.) required 45 hr of 83.5 hr.

[3] Low productivity in May '83 because: lot of mud (main reason), few trees per hectare, mostly mixed wood (lot of unmerchantable hardwood); long yarding distance (with smaller loads), big stumps from previous diameter logging.

[4] Wait for rear axle 68 hr.

Table 4. Repair Summary: Koehring Disc Saw on Koehring K2FF Feller Forwarder at Great Northern Paper Co., Portage, Maine.

	Dec. 1982	Jan. 1983	Feb.	Mar.	Apr.	May	June	July	Aug. 1983	Total	Comments
FELLING HEAD REPAIRS											
Structural											
Main frame or post											
Adaptor (between boom and felling head)											
Tree support (T-shaped)											
Pins & bushings											
Grab arms											
Upper	.5		2.5						1.0	4.0	- replace spring in grab arm in August.
Lower											
Protective saw cover		9.5								9.5	- saw cover pushed up - hit saw - 2 x in Jan.
Disc saw assembly											
Shaft & bearings											
Repair/Sharpen disc saw						2.0				2.0	- replace carbide tips on teeth (saw not removed)
Replace disc saw		1.5	1.0		2.0	1.0	2.5	2.0	1.0	11.0	- remove saw mainly to repair teeth or replace carbide tips.
Butt plate											
Other											
Hydraulic											
Disc saw motor											
Flexible hoses		2.0					3.5	1.5		7.0	
Fittings	1.5		4.5		1.0	.5				7.5	
Cylinders											
Upper grab arm											
Lower grab arm									4.5	4.5	- replace packing on cylinder (4.5 hr) in August.
Other			1.0							1.0	
Total Felling Head Repairs	2.0	13.0	9.0	-	3.0	3.5	6.0	3.5	6.5	46.5	
CARRIER REPAIRS											
Power and transmission unit	.5				2.0	4.0	3.0			9.5	- clutch slipping, 2 hr in Apr., clean engine compartment 3 hr in May, engine overheating (3 x) 3 hr in June.
Drive system (inc. tracks or wheels)		1.0				6.0	2.5		4.5	14.0	- install larger (39" wide) tires, 5 hr in May, replace rear drive motor, 2.5 hr in June, broken rear axle 4.5 hr in Aug.
Hydraulics on boom (only)	7.5	.5				7.0	9.0	1.5	2.0	27.5	- repl. crowd cyl. & hose, 6 hr in Dec., replace crowd cyl. 2.5 hr in May, replace crowd cyl. hose (4 x) 4 hr in June, repl. crowd cyl. hose and install bracket, 1.5 hr in Aug.
Hydraulics (general)	4.0	12.0	11.0		9.5	3.0	21.0	1.0	5.5	67.0	- repair hydr. drive line, 2 hr. in Jan. hydr. pressure problems, 4 hr in Apr. repl. valve, 3 hr in May, hydr. pressure problems (2 x) 11 hr in June, plug on oil tank came out - 1.5 hr in June repl. steering cyl. hose (2 x) 2 hr in June,hydr. pump for drive overheating, 1 hr in June. Repl. pump 2.5 hr in Aug.,O-ring on pump fitting 2.5 hr in Aug.
Electrical system	1.5	8.5	1.5	22.0	1.0	1.0	2.5	2.0	1.5	41.5	- repl. alternator, 6 hr in Jan., repair alternator & lights (4 x) 22 hr in Mar., repair lights (4 x) 2 hr in June.
Chassis & frame	3.0	13.0	3.0		2.5				2.5	24.0	- weld frame on dump body, 13 hr in Jan., repair alternator bracket, 2.5 hr in Apr., tighten cab bolts, 1.5 hr in Aug.
Booms											
Swing assembly	2.0	12.0								14.0	- repair fittings, 2 hr in Dec.
Other	7.5	4.5	2.0					1.0	.5	15.5	- repair cab heater, 4 hr in Dec.
Total Carrier Repairs	26.0	51.5	17.5	22.0	15.0	21.0	38.0	5.5	16.5	213.0	
TOTAL	28.0	64.5	26.5	22.0	18.0	24.5	44.0	9.0	23.0	259.5	

2. Several saw blade designs were tested before an acceptable version was found. Great Northern initially tried a one-piece blade with bent teeth having carbide tips and a multi-piece blade also with carbide tips. The new saw (see Fig. 7) design costs much less ($2400 each) and is now the "standard" blade marketed by Koehring for rock-free or relatively rock-free terrain. With the "standard" blade, damage to only a few teeth (i.e. carbide tips missing) has no significant effect on cutting. Carbide tips are relatively easy to replace until the "seat" is damaged. Then the tooth must be cut off and replaced. NOTE - This is a major problem if operating in rocky terrain.

3. Prior to FERIC's study, during his first week on the job, one operator struck a K2FF tire with a completely-tilted saw head, cutting through both tire and tire chain. Both tire and chain were subsequently repaired. In another incident, the operator hit the top of one of the front bunk stakes with the turning saw damaging the saw blade (see Fig. 2). The top of the bunk stake could be made of wood to prevent this from happening again. In each case considerable downtime resulted. Design changes by the manufacturer and attention by the operator can reduce or eliminate these potential problems.

GENERAL COMMENTS

Productivity: Of the Koehring disc heads at Dubreuil Bros. and at Great Northern Paper is summarized in Table 5.

Table 5. Productivity Comparison - Koehring Disc Saw.

	Koehring KFF feller forwarder at Dubreuil Bros. Dubreuilville, Ont.	Koehring K2FF feller forwarder (prototype) at Great Northern Paper Portage, Maine
Date of study	March - June 1982	Dec. 1982 - Aug. 1983
Volume per tree	.213 m^3	.213 m^3
Trees felled & forwarded/PMH	60	71
Productivity	12.7 m^3/PMH	15.1 m^3/PMH

Table 5 indicates that on a PMH basis, the productivity of the two disc-head equipped feller forwarders was similar, in spite of the smaller load size, longer forwarding distances and lower density stands harvested by the K2FF. The reasons for similar productivity can be attributed to several factors:

1. The re-designed disc head on the K2FF was capable of cutting all trees up to 50 cm in a "scything" motion, using only the boom swing control. In comparison, the older disc saw head (on the KFF) required simultaneous use of the main boom, stick boom and boom swing control to cut trees over 20 cm, which was much more difficult for the operator. As a result of the head re-design, the K2FF operators seldom dropped trees. The KFF with its older disc head often dropped trees; delays resulted from picking up these trees.

2. The K2FF had the cab and boom mounted on a turntable. The 360° swing permitted the operator to swing the shortest route to the bunk.

3. Terrain conditions were more severe and snow depth (1.2 m) was greater at Dubreuilville (KFF).

When compared to Koehring feller forwarder(s) equipped with "multi-tree" shear head(s) working for both companies nearby, the disc saw at Dubreuil Bros. (a converted shear head) had similar productivity as the shear unit. For the re-designed disc head used on the K2FF at Great Northern Paper the felling process was faster with the disc head than for shears.

Repairs: Repair levels on the two disc heads varied greatly. The high repair level on the Dubreuilville unit resulted mainly from testing new types of saw blades for Koehring Canada, from the rocky terrain (which frequently damaged the saw blades) and from the design limitations of the disc head. The disc saw head repairs or modifications averaged 44.5 hr per month during FERIC's 4-month study, comprising 64% of the repairs to the entire machine (see Table 4). The disc head on the K2FF at Portage, Maine, however, provided excellent results. Repairs or modifications to this disc head averaged less than 6 hours per month, representing 18% of the total repairs (see Table 4). This was attributed to several factors including the re-designed saw head, the improved saw blade, the relatively rock-free terrain and the fact that the K2FF was a more suitable carrier when using the "scything" technique of felling.

FERIC's 9-month study at Portage, Maine showed that in relatively rock-free terrain the Koehring disc saw on the K2FF provided felling productivity higher than for a similar shear-equipped carrier. The saw head and blade repairs were minimal, considering that this was the first re-designed head. Future disc heads built by Koehring will have several improvements including stronger gussetting on the saw cover.

With Koehring's "standard" disc blade minor damage to only a couple of teeth (i.e. carbide tips missing) had no significant effect on productivity. Missing carbide tips could be replaced with silver soldering until the "seat" was damaged. Teeth with damaged seats were cut off and replaced. This procedure required the disc blade to be removed and a spare disc to be installed; it worked very well for Great Northern's relatively rock-free conditions. For rocky or boulder-strewn terrain, the "standard" disc blade is not adequate, because the entire saw blade must be removed too often if one or more teeth are damaged. FERIC and Koehring staff have discussed the testing of alternative designs, including a rugged "bolt-on" tooth arrangement. If this proves feasible, it should be possible for the machine operator to change a damaged saw tooth in a few minutes, also, it may permit the disc saw to be used successfully on rocky terrain.

On the two feller forwarders studied by FERIC, overheating of the hydraulic oil was not a problem since both machines had adequate cooling systems. On other carriers, such as excavator units, potential buyers should pay particular attention to the hydraulic cooling system, since the standard cooler may not be adequate.

Suitability for Large Trees: During 1982 and 1983 there were several Koehring disc saw (55-cm capacity) heads mounted on Koehring 266 excavator-type carriers in regular operation in Oregon, Montana and British Columbia. NOTE: Koehring no longer markets this 55-cm (old design) version; they only sell the 50-cm version similar to that on the K2FF. Koehring have sold 12 of the 50-cm version in the second half of 1983 to B.C. loggers for mounting on various carriers including the Cat 225, 227, 235 and Hitachi UH122.

In February 1982, FERIC's western division carried out a detailed time study on a Koehring 266 disc saw feller buncher owned and operated by G. Peters near Frazer Lake, B.C. for West Frazer Mills. The terrain was relatively flat with .8 m of snow; there was little underbrush. During the timing periods, the operation felled trees at a rate of 140 trees/PMH, or 77 m^3/PMH, based on an average tree size of .55 m^3. *This was the highest production level measured by FERIC for any "non-shear" feller buncher in B.C.* [6]. Although this level of production was not maintained over the long term it does point out the productive potential of the Koehring disc head in larger trees.

The same machine and operator mentioned above was observed in regular operation by the author near Chetwynd, B.C., in October 1982, working for another West Frazer Mills sawmill. Stand conditions and production rates were estimated to be similar to those noted above. The fuzzy surface of the tree butts cut by the disc saw (especially when it was dull) was considered a problem for scaling on some logging operations since it was more difficult to determine the extent of butt rot and other defects (see Fig. 3).

Power and Carrier Requirements: The K2FF with its three hydraulic pumps, its "power beyond" feature on the hydraulics, and its series connections for less circuit interference provided ample power and a smooth felling cycle for the disc saw. The three pumps permitted selection of correct and independent oil flows for several functions. This was important for the disc felling method.

Generally, the disc head is best suited to a carrier with variable displacement pumps with a separate pump for the saw drive. The separate pump ensures adequate hydraulic power to the saw even when other functions, such as boom swing or the grab arms require hydraulic power at the same time as the saw. Fixed displacement hydraulic systems can also be used for the disc saw, but with somewhat less effectiveness.

A tree is cut with the Koehring disc saw mainly by using the flywheel principle, using the stored energy of the revolving disc. A 2-cm thick Koehring blade turning at 1000 RPM has about 400 kW/sec of energy available. This means a maximum of 400 kW if the severing time is 1 sec*. When idling (e.g. 1000-1200 RPM), the disc saw requires about 15 kW (20 hp) of hydraulic power. This constant hydraulic power demand may interfere with other hydraulic functions and makes it desirable to have a separate pump for the saw drive.

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* or 800 kW if the severing time is 0.5 sec.

When a large tree (e.g. 40 cm) is cut there is an immediate power demand from the saw motor (since the saw RPM will normally drop during cutting) to retain the 1200 RPM level. The more hydraulic power available to the saw, the smaller the saw stalling effect and the less time required for saw RPM to build up again. During cutting and immediately after cutting a minimum of 37 kW (50 hp) is required. A hydraulic capacity of about 75 kW (100 hp) is however recommended for the Koehring disc saw. The larger the tree, the greater the stalling effect on the saw, and the longer the time required for saw RPM to build up again. On the K2FF the operator never had to wait for saw RPM to build up. On other carriers having less suitable hydraulic systems, waiting may be necessary particularly when cutting large trees.

The power demand for the disc saw is increased if the teeth are damaged or very dull. Koehring Canada have noted that saw blade and shaft failures occurred on several early disc heads when cutting large hardwoods with a dull saw [5]. These components have since been strengthened and improved. Blade thickness and weight should also be considered. A heavier, 2.54 cm-thick blade will cut better than a 1.9 cm-thick blade (all other factors being equal) because the amount of stored energy in the thicker blade is greater. However, the additional weight of the thicker saw may not be desirable for the carrier's boom lift capacity.

Most excavator-type units (e.g. Drott 40, JD 693) used as feller bunchers in Canada's forest industry are equipped with gear-type, fixed displacement pumps. Recently Koehring has developed a hydraulic drive system for their disc head that is better suited to these carriers. It uses a variable displacement piston-type motor coupled with a reduction gearbox to provide the necessary torque and RPM required for the disc saw. The swash plate of the piston-type saw motor is set at the proper angle at the time of installation to provide suitable saw rotation speed (usually 1200 RPM) at normal engine working speed. Usually the saw motor is hooked up to one (or two) pump(s) while the grab arms (which require a flow of about 1.3 L/sec @ 17,000 kPa (20 gpm @ 2500 p.s.i.)) are hooked up to another pump. If the saw motor and grab arms operate from a common hydraulic source the saw (even when idling) will interfere with the grab arm operation. The grab arm must not act sluggishly because the tree must be grabbed immediately after if is severed. If not grabbed immediately, the tree will start to fall, exerting high moment forces on the partially closed grab arms.

Koehring Canada suggest that excavator carriers for the disc head have a minimum weight of 22,700 kg (50,000 lb) with 100 kW (135 hp) <u>net</u> engine power. NOTE - On all Koehring carriers (i.e. 266-FB, KFF, K2FF) an independant saw circuit is used which provides 1.8 L/sec @ 31,000 kPa (29 gpm @ 4500 p.s.i.).

To date there is no mechanical evidence to suggest that the "scything" technique used by the Koehring disc saw results in abnormal stress on the boom, boom pins or turntable. The tree is usually cut at the same speed as the moving boom, thus there is no problem with twisting action on the boom as a result of impact against trees.

HARRICANA CIRCULAR SAW

Harricana Métal Inc. built their first prototype circular saw felling head in early 1980, in response to a detailed proposal from FERIC. During 1980 and 1981 several prototype versions were built and tested. The development program is outlined in FERIC TN-58 [1].

The recent recession in the forest industry has provided Harricana Métal (and other manufacturers) with relatively few opportunities to sell saw felling heads. In July 1982, FERIC began a 5-month shift-level study at United Sawmill, Hearst, Ont., and a 7-month study at Abitibi-Price, Iroquois Falls, Ont. These data plus the results of a 2-day detailed time study at Matériaux Blanchette, Amos, Qué., provide the basis for this section.

In August 1983, Harricana Métal introduced two re-designed versions of their 50-cm capacity circular saw head. Both versions are equipped with a side tilt (wrist) cylinder as standard equipment. The "standard" version (2230 kg) was designed for eastern Canadian conditions; with the "heavy duty" version (2600 kg) for the longer, heavier trees of western Canada (see Appendix C and Fig. 8).

According to Harricana Métal, their "standard" saw felling head can be installed on most excavator-type carriers having a rated bucket capacity of .6 m^3 ($\frac{3}{4}$ yd^3) or more, and having a hydraulic capacity of 180 L/min (40 gpm) at 17,000 kPa (2500 psi). The "heavy duty" version requires a rated bucket capacity of .84 m^3 (1 yd^3), or more. The late 1983 list price of the two units (including side tilt and boom adaptor) are $46 500 and $48 800 respectively (f.o.b. Amos, Que.) installed on the carrier of the customer's choice.

UNITED SAWMILL, HEARST, ONT.

In July 1982 (when the Harricana and Denis circ. saw were introduced to their operation) United Sawmill owned and operated 10 shear-equipped, tracked excavator-type feller bunchers.

In July 1982, the Harricana circ. saw head (which weighed over 2500 kg) was installed on a 4-year old JD693. FERIC's study started in Sept. 1982. The main problem (resolved prior to FERIC's study) was frequent overheating of the hydraulic oil resulting from an inadequate cooling system.

The Harricana JD693 was operated about 60 km southeast of Hearst, a commuter operation from Hearst that worked on a 1-shift per day basis, 5 days per week. The terrain was typical Clay Belt; it consisted of flat ground (with no rocks) and supported extensive stands of black spruce. The terrain classification was 4.1.1. [4]. Average tree size was very constant during FERIC's study; it averaged .138 m^3 per tree, based on scaling results accumulated over several months.

There was only one operator, age 61, on the Harricana circ. saw during FERIC's 5-month study. He had 5 years experience on a company-owned Drott 40 shear feller buncher and was considered to be a good (but not excellent) operator by FERIC. Scheduled machine operating time was 7.5 hours per shift; all operators were paid on an hourly basis with no bonus. The results of FERIC's study are presented in Table 6 and 7.

Table 6. Shift Level Study Results: Harricana Circular Saw on JD693 at United Sawmill, Hearst, Ont.

		Sept. 1982	Oct.	Nov.	Dec.	to Jan. 20, 1983	Total
Scheduling							
Days Reported	(DY)	22	20	22	19	12.0	95
Scheduled Time	(HR)	174.0	143.0	165.0	142.5	90.0	714.5
Out-of-Shift Time	(HR)	2.0	1.0	-	-	2.5	5.5
Total Time	(HR)	176.0	144.0	165.0	142.5	92.5	720.0
Shifts/Day	(SH/DY)	←		1		→	1
Scheduled Hours/Shift	(HR/SH)	←		7.5		→	7.5
Machine							
Repair In-Shift	(HR)	10.5	10.5	9.0	5.5	0.5	36.0
Repair Out-of-Shift*	(HR)	2.0	1.0	-	-	-	3.0
Service In-Shift	(HR)	10.5	9.5	10.0	9.0	5.0	44.0
Service Out-of-Shift	(HR)	-	-	-	-	-	-
Operations							
Non-Prod. Operating Time	(HR)	-	-	4.0	-	-	4.0
Wait Parts	(HR)	-	-	-	-	-	-
Wait Mechanic	(HR)	1.5	-	-	-	-	1.5
Miscellaneous Delays	(HR)	23.5	12.0	43.0	32.5	31.5	142.5
Machine and Operations							
PMH In-Shift	(HR)	128.0	111.0	99.0	95.5	53.0	486.5
PMH Out-of-Shift	(HR)	-	-	-	-	2.5	2.5
CPPA Availability	(%)	87	86	88	90	94	88
Mechanical Availability	(%)	85	84	84	87	90	85
Utilization	(%)	74	78	60	67	59	68
Total Time Utilization	(%)	73	77	60	67	60	68
Production							
Total Production	(m^3 (ct))	2309 (815)	1950 (689)	2111 (746)	2188 (772)	1246 (440)	9804 (3462)
Trees Harvested	(TR)	16,625	14,040	15,200	15,750	8,970	70,585
Volume per Tree	(m^3 (ft^3))	←		.138 (4.9)		→	.138 (4.9)
Trees per PMH	(TR/PMH)	130	126	154	165	162	145
Productivity	(m^3/PMH) (ct/PMH))	18.1 (6.4)	17.5 (6.2)	21.4 (7.6)	22.9 (8.1)	22.5 (7.9)	20.2 (7.1)

* Some non-felling related out-of-shift repairs to the carrier were not recorded in this study.

Table 7. Repair Summary: Harricana Circular Saw on JD693 at United Sawmill, Hearst, Ont.

		Repair Time (hrs)						Comments
		Sept 1982	Oct.	Nov.	Dec.	Jan. 1983	Total	
FELLING HEAD REPAIRS								
Structural								
Boom adaptor	1							
Track & roller unit								
Upper section & tracks	2							
Vertical posts	3							
Lower section (protect. plate)	4							
Upper roller ass'y	5							
Lower roller ass'y	6							
Main frame (or post)	7					0.5	0.5	reinforce centre of post
Tree support (T-shaped)	8							
Pins & bushings	9							
Grab arms (2)	10							
Tree accumulator arm	11							
Protective plates	12	5.0					5.0	reinforce bottom of head
Saw cover (above saw)	13							
Saw cover (below saw)	14							
Butt plate	15							
Circular saw assembly								
Shaft & bearings	16							
Repair/adjust saw	17							
Sharpen saw	18	1.5					1.5	sharpen saw
Clear debris from saw	19							
Replace saw	20			4.0			4.0	broken tooth - replace saw
Other	21							
Other	22							
Hydraulic								
Flexible hoses								
Between boom & head	23	5.0	0.5				5.5	change hose (8 x)
Other	24							
Fittings	25	1.0					1.0	tighten fittings (2 x)
Motor, circular saw	26							
Cylinders								
Grab arms (2)	27							
Accumulator arm	28							
Track & roller	29							
Controls (for felling head)	30							
Other	31							
Sub total: felling head)		12.5	0.5	4.0		0.5	17.5	
CARRIER REPAIRS *								
Power & transmission unit	32				5.5		5.5	fuel lines dirty
Drive system (incl. tracks or wheels)	33							
Hydraulics on boom (only)	34			5.0			5.0	replace crowd cylinder (rod end broken)
Hydraulics (general)	35		2.5				2.5	
Electrical system	36		0.5				0.5	change toggle switch on control
Chassis & frame	37							
Booms	38							
Turntable/swing ass'y (if appl.)	39		8.0				8.0	repair rotor on swing ass'y
Other	40							
Sub total: carrier			11.0	5.0	5.5	0.5	21.5	
TOTAL		12.5	11.5	9.0	5.5	0.5	39.0	

* Some non-felling related out-of-shift repairs to the carrier were not recorded in this stud

Production: The productivity averaged 145 trees/PMH, or 20.2 m^3/PMH, based on an average tree size of .138 m^3. The trees/PMH in the first two months averaged 130, but this increased to 160 during the last two months. The increase was attributed mainly to increased operator experience and skill.

NOTE: Compared to three shear-type feller bunchers (a Drott 40/Drott shear, JD693/Harricana shear and a Int. 3964/Forano shear) also operating at the same camp, the Harricana circ. saw/JD693 usually had similar or slightly higher production than the best of the shear machines. This comparison was based on United Sawmill's production data for these machines for Oct., Nov. and Dec. 1982. It applies to gross monthly production and to production on a PMH basis. All these machines were operated close together in similar conditions by experienced, hourly-paid operators.

Repair: *Prior to FERIC's Study* (Aug. 1982) the main problem was overheating of the hydraulic oil. When the oil was overheated, the circular saw would cut only half way through a large tree, instead of going through completely. In addition to oil pressure loss and reduced cutting efficiency, overheating resulted in premature failure of hydraulic components (e.g. O-rings) and high cab temperatures. United Sawmill solved the overheating problem by adding a second oil cooler using a spare pulley on the drive shaft to power a second fan (see Fig. 6).

During FERIC's Study the saw head worked well, although some improvements were made as experience was gained. The hydraulic hoses at the back of the felling head caused some problems. Also, during the winter some small cracks appeared at the base of several teeth on the original saw blade. These were welded and the saw was put back on again.

After FERIC's Study (in Feb., 1983) Harricana Métal carried out a number of modifications (observed in March 1983 by FERIC):

1. The original saw blade was replaced with one having 58 teeth and centre rakers. This saw made a cleaner cut and operated much more quietly.
2. Brass guides were placed on the cover plate to prevent the saw from striking its cover (see Fig. 6).
3. A brace was added to the front of the front cylinder mount.
4. The standard pumps on the JD693 (2 at 42 gpm) were replaced with two 48 gpm Commercial Shearing gear-type pumps to obtain more power when cutting large trees.

After FERIC's Study (July-Aug. 1983) the Harricana circ. saw head was completely re-designed based in part on the experience with the United Sawmill and Abitibi-Price units which is described in this report.

ABITIBI-PRICE, IROQUOIS FALLS, ONT.

A Harricana circ. saw mounted on a leased Timbco 2518 tracked carrier was operated by Abitibi-Price starting in July 1982; FERIC data was collected from August 1982 to February 1983. The Timbco carrier was chosen by Abitibi mainly because of its good flotation characteristics on soft ground. The Harricana circular saw was chosen because trees free of butt shatter were required for the company stud mill at Smooth Rock Falls, Ont. [5]. The introduction of the Harricana circ. saw/ Timbco was part of a programme to initiate mechanized felling, grapple skidding and mechanized delimbing at this division of Abitibi-Price. Thus, the inexperience of the operators, mechanics and supervisors with mechanized logging was a (negative) factor on this operation.

The Timbco 2518 was not designed to handle a heavy felling head like the Harricana circ. saw (which at that time weighed 2500 kg); therefore the stick boom was shortened by .58 m. FERIC's data indicates however that the Harricana head was still too heavy for the Timbco. The Harricana/Timbco was returned to the dealer at the end of the 10-month lease period because of the high repair levels that occurred. NOTE - In December 1983, Abitibi-Price's second Timbco (a stronger-built unit with a Cat 235 undercarriage - see p.35) had its Denis head replaced with a lighter "standard" version Harricana circ. saw head. Results to date with this new machine have been good. The lift capability of this unit with the boom fully extended was not a problem.

The Harricana/Timbco operated at Abitibi's Camp 40 located about 40 km north of Timmins. The terrain was typical Clay Belt (similar to that at United Sawmill's harvesting area); it consisted of flat ground with no rocks and supported extensive stands of even-age black spruce. The terrain was classified as 4.1.1 [4]. The average tree size during FERIC's study was .150 m^3.

The Harricana/Timbco was operated on a 2-shift per day basis, 5 days per week. During the first few months there were several union employees who wanted only to become "qualified" operators; thus there was a lot of operator turnover. The uncomfortable working environment in the cab (high heat level) was a significant factor in operator turnover during the first few months. All operators were paid on an hourly basis with no bonus provision. A discussion of the results follows.

Production: The average productivity during FERIC's 7-month study was 102 trees/PMH, or 15.3 m^3/PMH, based on an average tree size of .15 m^3. The lowest productivity occurred in the first few months of the study mainly because of operator turnover and subsequent training activities. The higher production in Nov. and Dec. 1982 (116 and 121 trees/PMH) reflected increased operator experience. In January 1983 new operators were trained; thus the productivity dropped to 92 trees/PMH.

Repairs: During FERIC's study there were 169.5 repair hours on the Harricana circ. saw head and 292 repair hours on the Timbco. This level of repairs was much higher than expected but could be attributed to several factors:

1. The (small) Timbco carrier was not designed to be equipped with a heavy felling head, such as the Harricana saw head (2500 kg). Even though the Timbco boom was shortened by .58 m there were major structural failures in the boom, turntable and frame. For example, in Feb. 1983 there were 69.5 repair hours on metal cracks at the base of the main boom and 27 repair hours to replace the main boom cylinder. *In the three months after FERIC's study*, Abitibi-Price reported frame cracking problems (about 100 repair hours) in the turntable/frame area.

Table 8. Shift Level Study Results: Harricana Circular Saw on Timbco at Abitibi-Price, Iroquois Falls, Ont.

		Aug. 1982	Sept.	Oct.	Nov.	Dec.	Jan. 1983	Feb.	Total
Scheduling									
Days Reported	(DY)	19	19	22	21	15	19	19	134
Scheduled Time	(HR)	304.0	304.0	352.0	346.0	270.0	310.0	358.0	2244.0
Out-of-Shift Time	(HR)	3.0	1.5	–	–	–	–	–	4.5
Total Time	(HR)	307.0	305.5	352.0	346.0	270.0	310.0	358.0	2248.5
Shifts/Day	(SH/DY)	←			2			→	2
Scheduled Hours/Shift	(HR/SH)	←			8.5			→	8.5
Machine									
Repair In-Shift	(HR)	66.0	36.5	39.0	76.0	50.0	33.5	158.0	459.0
Repair Out-of-Shift	(HR)	1.0	1.5	–	–	–	–	–	2.5
Service In-Shift	(HR)	16.0	17.5	20.0	20.0	15.5	21.0	15.0	125.0
Service Out-of-Shift	(HR)	–	–	–	–	–	–	–	–
Operations									
Non-Prod. Operating Time	(HR)	10.0	9.0	29.5	11.0	10.5	12.0	6.5	88.5
Wait Parts	(HR)	10.0	–	1.0	–	–	2.0	1.0	14.0
Wait Mechanic	(HR)	10.0	1.5	7.5	16.0	–	3.0	–	38.0
Miscellaneous Delays	(HR)	41.0	35.0	28.5	21.5	34.0	20.0	17.5	197.5
Machine and Operations									
PMH In-Shift	(HR)	151.5	204.5	226.5	201.5	160.0	218.5	160.0	1322.5
PMH Out-of-Shift	(HR)	1.5	–	–	–	–	–	–	1.5
CPPA Availability	(%)	66	82	81	68	76	81	51	72
Mechanical Availability	(%)	65	79	79	68	71	80	48	69
Utilization	(%)	50	67	64	58	59	70	45	59
Total Time Utilization	(%)	50	70	64	58	59	70	45	59
Production									
Total Production	(m^3 (ct))	1548 (546)	3118 (1101)	3239 (1144)	3500 (1236)	2849 (1006)	3004 (1061)	2918 (1030)	20,176 (7124)
Trees Harvested	(TR)	10,826	20,358	21,053	23,309	19,375	20,129	19,548	134,598
Volume per Tree	(m^3 (ft^3))	.143 (5.0)	.153 (5.4)	.153 (5.4)	.150 (5.3)	.147 (5.2)	.149 (5.3)	.149 (5.3)	.150 (5.3)
Trees per PMH	(TR/PMH)	71	100	93	116	121	92	122	102
Productivity	(m^3/PMH (ct/PMH))	10.1 (3.6)	15.2 (5.4)	14.3 (5.0)	17.4 (6.1)	17.8 (6.3)	13.7 (4.8)	18.2 (6.4)	15.3 (5.4)

Table 9. Repair Summary: Harricana Circular Saw on Timbco at Abitibi-Price, Iroquois Falls, Ont.

		Repair Time (hrs)								
		Aug. 1982	Sept	Oct.	Nov.	Dec.	Jan. 1983	Feb.	Total	Comments
FELLING HEAD REPAIRS										
Structural										
Boom adaptor	1									
Track & roller unit										
Upper section & tracks	2									
Vertical posts	3									
Lower section (protect. plate)	4						1.0		1.0	
Upper roller ass'y	5	.5		10.0	12.0				22.5	- roller came off bearing (Aug.); tighten ass'y (Oct.), replace (Nov.)
Lower roller ass'y	6							9.5	9.5	- welding on lower roller ass'y
Main frame (or post)	7									
Tree support (T-shaped)	8				1.0				1.0	- welding on tree support
Pins & bushings	9									
Grab arms (2)	10					.5			.5	
Tree accumulator arm	11									
Protective plates	12									
Saw cover (above saw)	13									
Saw cover (below saw)	14	2.5	1.5						4.0	- weld saw cover below saw (3 x)
Butt plate	15									
Circular saw assembly										
Shaft & bearings	16						5.0	1.5	6.5	- tighten saw bearing (Jan.)&(Feb.)
Repair/adjust saw	17	.5						1.0	1.5	- straighten saw teeth
Sharpen saw	18		1.5		1.5	2.0			5.0	
Clear debris from saw	19									
Replace saw	20	1.0		1.5		1.5	4.0	5.0	13.0	- cracks in saw at base of teeth in Jan. & Feb.
Other	21									
Other	22	1.0	1.0	1.0					3.0	- install protective bar (Oct.)
Hydraulic										
Flexible hoses										
Between boom & head	23	3.5	4.5		3.0	7.5	3.0	6.5	28.0	- repair/replace hoses (40 x)
Other	24		3.5	3.0	9.5		2.0	10.0	28.0	- repair/replace hoses (32 x)
Fittings	25	.5	1.5	2.5	.5		1.5	5.0	11.5	- tighten/replace fittings (20 x)
Motor, circular saw	26		4.5			.5			5.0	
Cylinders										
Grab arms (2)	27	1.0				1.0			2.0	
Accumulator arm	28				11.5	2.5			14.0	- change oil seal for accum. arm cyl. (Nov.)
Track & roller	29			2.0					2.0	
Controls (for felling head)	30	3.0				1.0		6.0	10.0	- repair controls (Aug.), replace felling head control switch (Feb.)
Other	31	.5	1.0						1.5	- repair electric saw brake (Aug.)
Sub total: felling head		14.0	19.0	20.0	39.0	16.5	16.5	44.5	169.5	
CARRIER REPAIRS										
Power & transmission unit	32	1.0		2.0		18.0	.5		21.5	- repair clutch 18 hr, Dec.
Drive system (incl. tracks)	33		1.0			13.5	5.5	9.0	29.0	- repair track guard bolts 3 hr, replace track idler 9 hr, tighten track pads 1.5 (all in Dec.); replace track pins (2 x) 5.5 hr, Jan., replace transmission valve 7 hr (in Feb.)
Hydraulics on boom (only)	34	.5	1.5	10.5	1.0		6.0	27.0	46.5	- replace main boom cylinder 27 hr (Feb.)
Hydraulics (general)	35	37.5	12.5		14.5	1.0	1.5	6.0	73.0	- hydraulic oil overheating (8 x) move oil cooler from top of cab back to radiator, install a larger radiator fan, replace block valve, O-rings replaced on block valve (3 x) Aug.& Sept., oil cooler broken 14.5 hr, Nov., replace hydr. pump gasket, Feb.
Electrical system	36	5.5	3.5	1.5		1.0	3.5	2.0	17.0	- replace alternator (2 x) in Aug., fix lights (5 x) in Sept., fix lights (4 x) in Jan., repair short circuits.
Chassis & frame	37	2.5	.5						3.0	
Booms	38	6.0						69.5	75.5	- main boom cracked at base (Aug.), welding and replace main boom section in Feb.
Turntable/swing assembly	39				4.5				4.5	- replace swing assembly motor
Miscellaneous	40			5.0	17.0				22.0	- install air conditioner in cab, Oct., replace radiator 4 hr, repair cooling system 7.5 hr, replace wiper motor, install cab heater, replace windshield, all in Nov.
Sub total: carrier		53.0	19.0	19.0	37.0	33.5	17.0	113.5	292.0	
TOTAL		67.0	38.0	39.0	76.0	50.0	33.5	158.0	461.5	

The lift capability of the Timbco was inadequate with the Harricana circ. saw head since it could not lift a tree(s) when the boom was more than 60% extended. To lift and pile one or more severed trees the operator had to retract the boom 1-2 m before lifting the head. This limitation prevented the operator from developing a good felling pattern; it also contributed to high repair levels because the hydraulic hoses at the back of the head tended to snag on debris or broken trees (see Fig. 6) and reduced the productivity.

2. The hydraulic system on the Harricana/Timbco was installed incorrectly by the local Timbco dealier. The main body valves were installed in series rather than in parallel. As a result, when the boom was used the oil pressure to the saw was reduced. Consequently the operator had to wait for the saw to build up to operating RPM (1200) before cutting each tree. This contributed to the low productivity and to problems with hydraulic oil overheating. The problem was rectified in late Sept. 1982.

3. Hydraulic oil overheating and its accompanying problems was a major cause of downtime right from the beginning. The oil overheating problem was most severe in warm weather but also occurred during other periods of the year. Overheating contributed to operator discomfort because the hydraulic hoses in the cab threw off a lot of heat.

The basic problem was that the Timbco's hydraulic system did not have adequate cooling capacity. The oil cooler, mounted in front of the radiator, plugged up easily with fine dust and debris because a suction-type fan pulled the outside air through the oil cooler and radiator into the engine area. Even when not plugged this oil cooler was barely adequate. Prior to FERIC's study the local Timbco dealer tried moving the oil cooler to behind the operator's cab, but it was later returned to its original position. A larger fan and screen was added and a compressed air unit was installed on the cab to help keep the cab temperature more comfortable. This helped but did not fully rectify the problem.

The repair hours required because of overheating of the hydraulic oil were considerable. In Table 9 many of the 73 repair hours to the carrier under *hydraulic-general* (35) and *miscellaneous* (40) are a direct result of hydraulic oil overheating. The productivity suffered from system inefficiency owing to pressure losses when overheating occurred and from operator fatigue and discomfort. To date there has been no satisfactory solution to the hydraulic oil overheating problem. It has been reduced but not eliminated.

There were also problems with the Harricana circular saw head:

Hydraulic Hoses: The hydraulic hoses and fittings at the back of the Harricana felling head required frequent repairs (approx. 90 repairs totalling 66 repair hours - see Table 9). This high repair level was attributed to several factors. Firstly, the Timbco could not lift the Harricana head with one or more trees at full boom extension. Therefore, the operator had to pull the head back 1-2 m before lifting. The hoses tended to snag on broken trees or debris when the head was pulled back, particularly when operating in deep snow. Secondly, these hoses were constantly flexed in a tight curve. In winter, with ice build-up from melted snow on the lower guard plate, the hoses would rub against the ice causing chaffing and premature hose breakage. A metal plate hose guard was later installed to protect the hoses from falling snow (from trees being felled) reducing the problem. NOTE: The re-designed Harricana circular saw head (August 1983) has virtually eliminated the hose maintenance problem (see Fig. 8 and Appendix C).

Saw Blade: There were six saw blades used by Abitibi-Price during the 7-month study period. Most of these were replaced by Harricana Métal because the saw head and its saw was regarded as an early production unit. The replacement cost of saw blades is $1400.

Saw 1 and 2: these saws hit the bottom of the front of the saw cover when it was bent. This problem was corrected by reinforcing the front of the saw cover and by adding brass guides for the saw (see Fig. 9).
Saw 3: hit a mining drill casing; operator error.
Saw 4: (Nov. 1982) cracks at the base of some teeth - several teeth eventually broke off - replaced saw.
Saw 5: (Dec. 1982) cracks at the base of some teeth - replaced saw.
Saw 6: (Jan. 1983) cracks at the base of some teeth - replaced saw.

NOTE: Harricana Métal attributed the cracks at the base of the teeth on saws Nos. 4, 5 and 6 to inadequate carbon content in the steel - a quality control problem. A new 36-tooth saw blade 1.27-cm thick made of alloy steel has been developed by Harricana Métal. Experience by several companies using this saw during the 9-month period (Mar. - Dec. 1983) following FERIC's study was excellent; no cracks developed in the blade. However, cold weather results are not available yet.

MATÉRIAUX BLANCHETTE LTÉE, AMOS, QUÉ.

A detailed time study was conducted by FERIC on a 2500-kg Harricana circ. saw head on a JD693 carrier being used for a 2-month trial near Amos in Sept. 1982. The carrier was normally equipped with shears and was owned by Mr. Yves Brière, a large logging contractor who supplied Matériaux Blanchette Ltée, a sawmill in Amos. The saw head was not purchased mainly because the depressed lumber market (at that time) did not permit capital expenditures.

Table 10 indicates that the terrain was quite similar to that described earlier for United Sawmill (Hearst) and Abitibi-Price (Iroquois Falls) except for the prescence of a dense willow/alder understory. The average tree size was larger; it averaged .194 m^3.

The Harricana/JD693 was operated on a 2-shift per day basis, 5 days per week. The operators on both shifts were experienced (shear-type) feller buncher operators who had little problem adjusting to the circular saw. The saw feller buncher was equipped with full joystick controls using Monson-Tyson valves mounted on top of the regular valve bank. It was reported by the foreman that the JD693 had not experienced hydraulic oil overheating problems. This was attributed to the installation of a 2-way, reversible fan having increased pitch, plus a larger oil cooler. NOTE: Both of these items are available from John Deere Ltd. in a kit costing about $1000 or can be supplied on new carriers. The JD693 was equipped with standard hydraulic pumps.

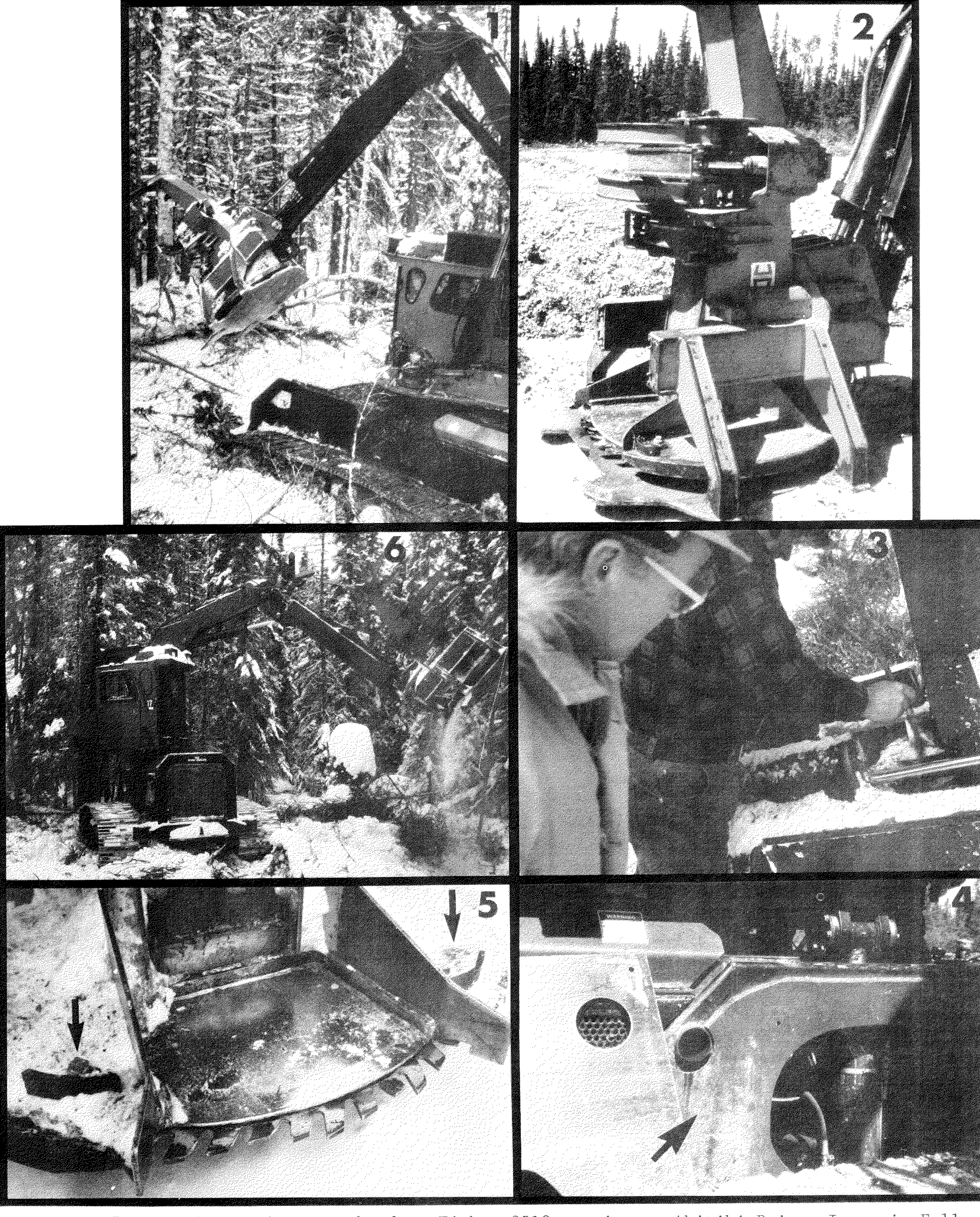
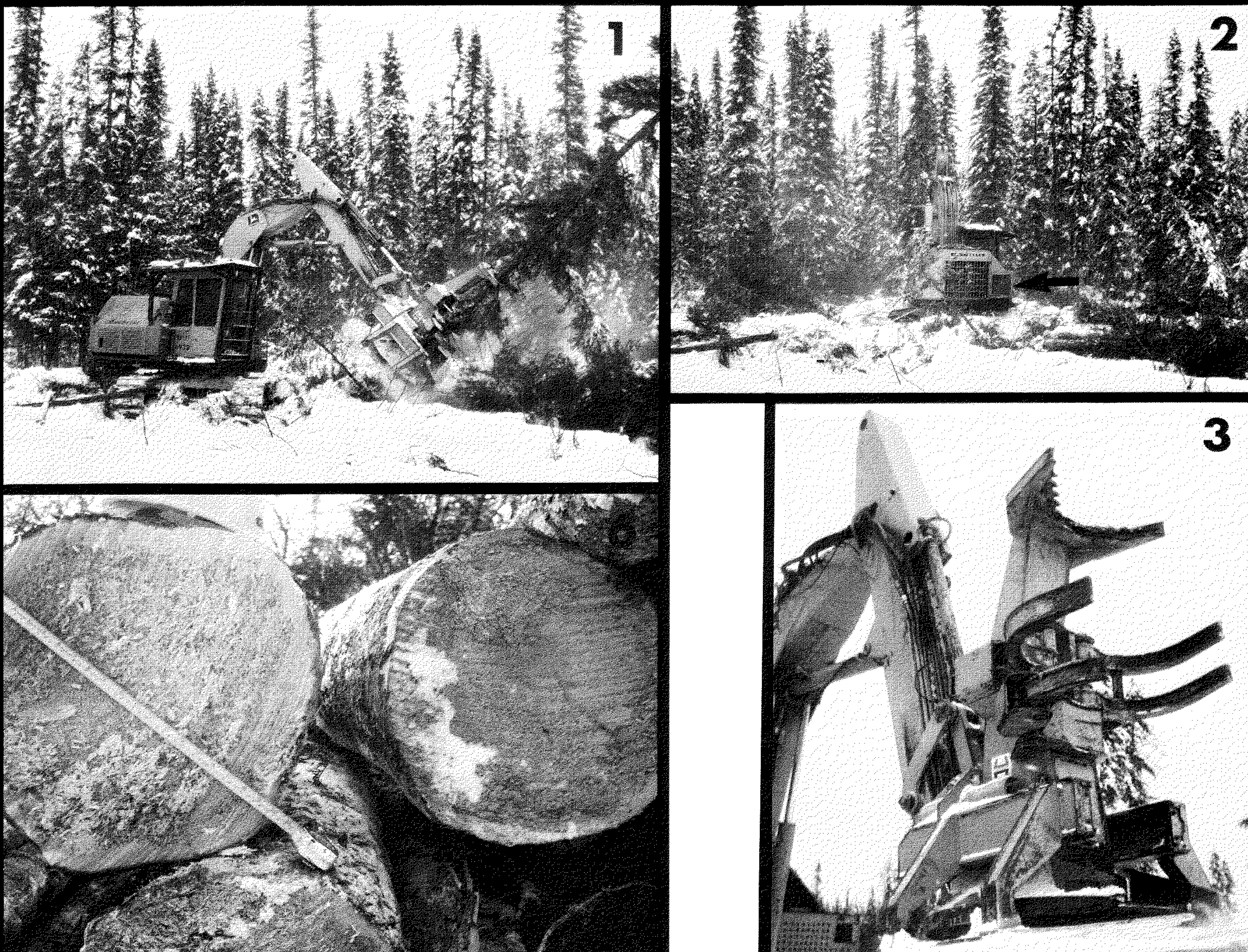


Fig. 7. Harricana circ. saw head on Timbco 2518 carrier at Abitibi-Price, Iroquois Falls, Ont.; 1, 2 & 6: the (2500 kg) Harricana head was too heavy for this (relatively small) carrier... several problems with the boom and frame resulted despite shortening the stick boom .58 m; 3: snow packing behind the head required periodic cleaning; 4: bracing was added to frame (see arrow); 5: adjustable brass guides (see arrows) prevent saw flutter; also note butt plate above saw.



ig. 6. Harricana circ. saw head on JD693 at United-Sawmill, Hearst, Ont.; 1: felling and unching in a black spruce stand; 2: arrow shows location of the second oil cooler; 3: arricana circ. saw head after 8 months of use; 4 & 5: hydraulic hose failure at the back of he felling head was a major cause of repair downtime. This problem has been eliminated on he new design (see Fig. 8); 6: trees up to 50 cm (20 in) butt diameter were felled with irtually no butt damage. Note the rough, frayed surface made by the saw.

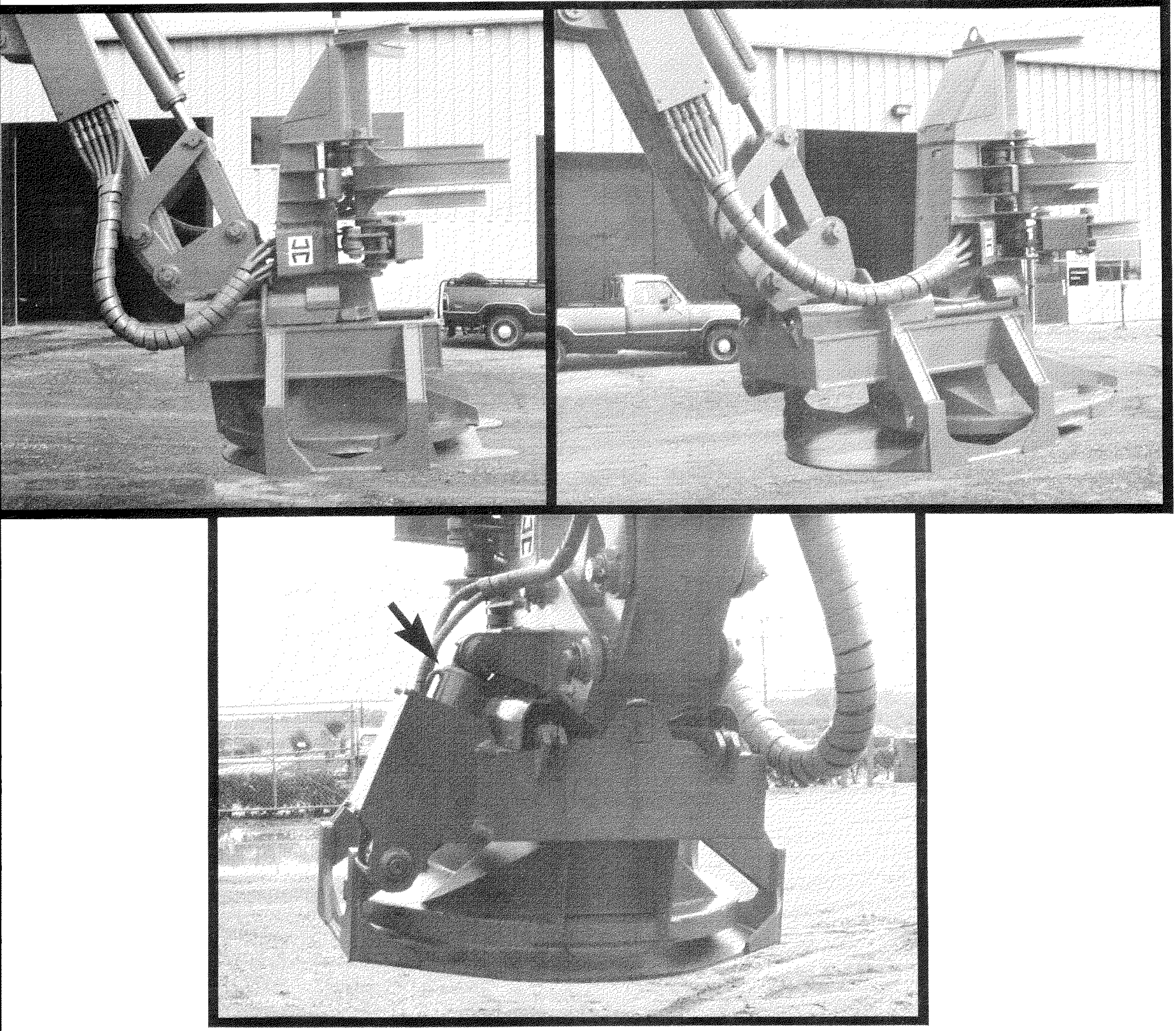


Fig. 8. New design of Harricana circ. saw head (Aug. 1983) - "heavy-duty" version. The main changes, as compared to the units shown in Fig. 6 and 7 are: the hoses to the head are relocated and reduced in number from 9 to 5 (the saw uses direct hydraulics - the saw feed, grab arms and accumulators arms are activated by solenoid valves on the head); a 15^{o} tilt cylinder (with separate hosing) is added (see arrow); boom adaptor is re-designed - the head is now 15 cm closer to the carrier (reducing the moment on the boom); grab arms rounder in shape; considerable reduction in weight (see Appendix C for details).

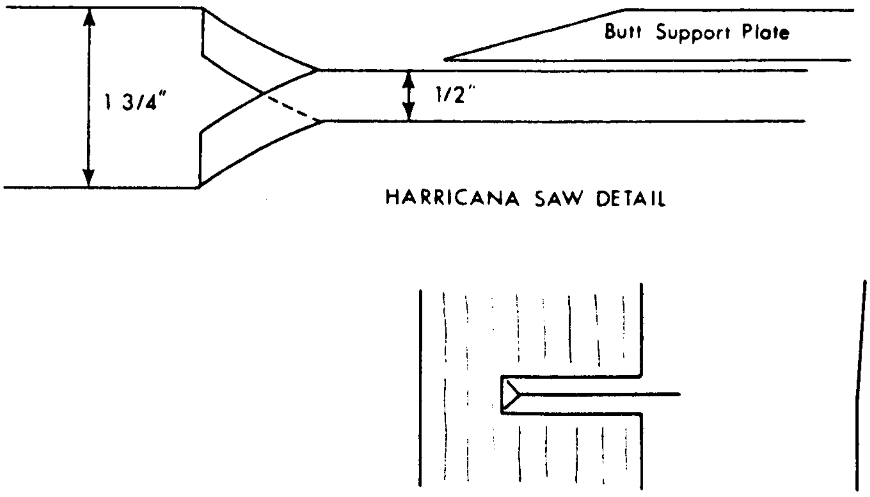


Fig. 9. The Harricana circular saw does not bind even if the kerf closes tightly. From Guimier [8].

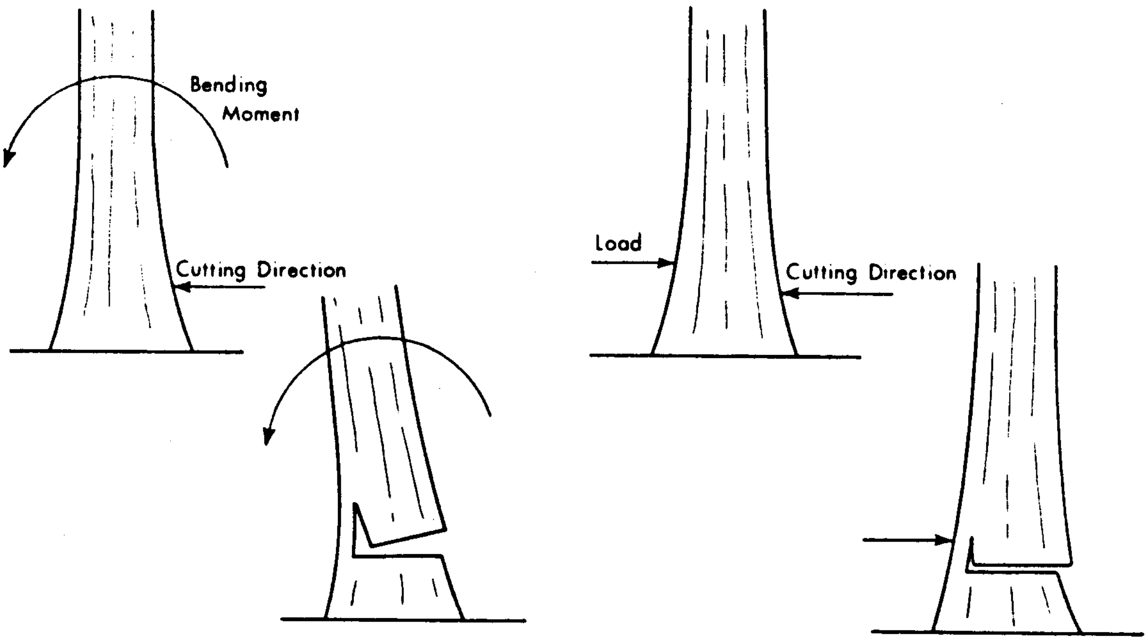


Fig. 10. Bending moment and/or loads perpendicular to the tree during the cutting phase result in butt damage. This applies to all types of felling heads. From Guimier [8].

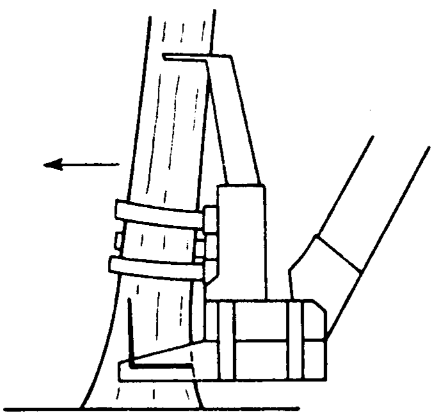


Fig. 11. Harricana head. A tree leaning toward the machine can be pushed and damaged as the saw is fed into the tree (grab arms are open). From Guimier [8].

Table 10. Stand and Terrain Factors.

	Harricana Circular Saw/JD 693 at Matériaux Blanchette Ltée, Amos, Qué.
Location	80 km northeast of Amos
Study date	September 8, 9, 1982
Stand type	clearcutting
Species	black spruce 100%
Trees per hectare	600 (estimated) - heavy understory of 3-4 m high willow & alder
Volume per tree	.194 m^3 (6.8 ft^3)
Terrain	lowland, classified as 4.1.1 [4]

Table 11. Production Summary

	Harricana Circular Saw at Matériaux Blanchette Ltée, Amos, Qué.	
	time per tree, cmin	%
Move empty	15.3	35
Felling & piling	17.6	40
Move between trees	1.9	4
Move for piling	7.0	16
Delays	2.1	5
Total time per tree	43.9	100%
Duration of study, hr	11.16 PMH	
Total trees harvested	1525	
Total cycles	724	
Cycles/PMH	65	
Trees/cycle	2.11	
Trees/PMH	137	
Volume/PMH	26.5 m^3	

Production: The productivity during FERIC's 2-day study averaged 137 trees/PMH or 26.5 m^3/PMH based on an average tree size of .194 m^3. The productivity was less than expected mainly because the 3-4 m high willow and alder understory reduced operator visibility. Some difficulty was experienced when cutting large trees (over 35 cm dbh) because the saw blade had a tendency to "power out" or stall. Sometimes a large tree would be dropped. Productive time was lost in picking up dropped trees, because the grab arm configuration made this operation difficult.

One of the two operators studied had a tendency to accumulate too many trees in the felling head. In such cases the last tree might be only partially (¾) cut and would be pulled off its stump, causing a split in the butt portion of the tree which reduced its value for lumber.

Although not observed by FERIC, some experience was obtained nearby on hilly ground. The foreman of this operation reported that on hilly terrain the production of the (2500 kg) circular saw head was lower than for a shear because of the lack of a side-tilt cylinder on the saw head and because additional swing power was desirable when working on downhill slopes. Because no side tilt was available on the head (or carrier) additional time was spent in manoeuvering the carrier to approach a standing tree from the proper direction.

GENERAL COMMENTS

Production: The results are summarized below:

Table 12: Production Comparison-Harricana Saw Head*.

	JD693 carrier United Sawmill Hearst, Ont.	Timbco 2518 carrier Abitibi-Price Iroquois Falls, Ont.	JD693 carrier Matériaux Blanchette Amos, Qué.
Duration of study	5 months	7 months	2 days
Type of study	shift level	shift level	detailed
Volume per tree	.138 m^3	.150 m^3	.194 m^3
Trees/PMH	145	102	137
Productivity	20.2 m^3/PMH	15.3 m^3/PMH	26.5 m^3/PMH
CPPA Availability	88%	72%	N/A
Mechanical availability	85%	69%	N/A
Utilization	68%	59%	N/A

* All three machines worked in black spruce stands on relatively flat terrain. A dense willow/alder undergrowth reduced the potential productivity for the Amos unit.

The large difference in productivity between the United Sawmill unit (145 trees/PMH; 20.2 m^3/PMH) and Abitibi-Price unit (102 trees/PMH; 15.3 m^3/PMH) can be explained:

1. There was only one operator on United Sawmill's machine during its study. For Abitibi's unit (2 shifts/day) there were 6 or 7 different operators. Since it took a new operator up to 3 months to become fully proficient on the Harricana/Timbco, operator training tended to reduce its productivity.

2. The Timbco carrier was unable to lift one (or more) trees in the Harricana felling head when at full boom extension; the head had to be pulled back 1-2 m before raising it. This reduced productivity.

3. During the first part of FERIC's study the hydraulics on the Abitibi unit were not hooked up properly; this caused delays waiting for saw RPM to build up.

Large Trees: For large trees (those close to the 50-cm capacity of the Harricana circ. saw) there was limited experience with the three units studied by FERIC. For the JD693 at United Sawmill FERIC noticed that the 58 tooth saw blade slowed down or stalled when cutting 40-50 cm trees, particularly if the teeth were dull. Two improvements were made. First, to obtain additional cutting power John Deere Ltd. and Harricana installed larger pumps (2 @ 45 GPM) on United's JD693 after FERIC's study; the results have been good. (Starting in Feb. 1984, the JD693 will be available with the larger pumps (2 @ 45 GPM) as standard equipment.) Secondly, the use of the 36 tooth "standard" blade with centre rakers required less cutting power. Now large trees up to 50 cm can be cut with no significant stalling effect.

In respect to operating in large tree sizes, it is useful to mention the main results of a 5-month shift level study done by Mr. Bruce McMorland of FERIC's western division during July 27 to Dec. 22, 1982. A Harricana 51-cm circ. saw head (identical to those studied in eastern Canada) mounted on a Drott 40 was owned and operated by Mr. G. Vetter, a Weyerhauser logging contractor near Kamloops, B.C. The average productivity was 102 trees/PMH, or 44.7 m^3/PMH, based on an average tree size of .44 m^3. This feller buncher was observed by the author in October 1982; it was still in use at the time of writing (Nov. 1983). The complete results of this study will likely be published at a later date.

Mechanical Availability: On Abitibi's Harricana/Timbco the mechanical availability was much lower than for United's Harricana/JD693. This was mainly because the Timbco was not a suitable carrier for the heavy (2500 kg) Harricana circ. saw head; extensive boom, turntable and frame cracking problems resulted. Both carriers however experienced hydraulic oil overheating problems. On United Sawmill's JD693 this was corrected by adding a second oil cooler. On Abitibi's Timbco several improvements were made to the oil cooling system but the problem was not fully resolved. On the Matériaux Blanchette JD693 a larger capacity oil cooler and a better fan (available as a package from JD) were installed for the circular saw: the results were reported to be good. NOTE - A potential Harricana saw user should specify a large-capacity oil cooling system on the carrier.

The Harricana saw head and saw blades also contributed to the total downtime. The hydraulic hoses at the back of the felling head were the greatest cause of downtime. This problem has been resolved by Harricana on their newly-designed units (see Fig. 8). The United Sawmill Harricana/JD693 studied by FERIC was retro-fitted with the new hydraulic hose/valve package in July 1983. They have reported no hose problems during the 5 months following the conversion (after FERIC's study).

A second problem with the Harricana circ. saw head was with the saw blade particularly for the Abitibi-Price machine. Fatigue cracks appeared at the base of the saw teeth and in some cases (particularly in sub-zero weather), the saw teeth broke off. Harricana Métal have attributed this to inadequate carbon content in the steel, a quality control problem. Their new "standard" saw design which has 36 teeth, is 1.27-cm thick, centre rakers and is made of alloy steel, has provided much superior results. These claims need to be substantiated by actual operating experience during the 1983-1984 winter. Results to date however have been good.

Butt Damage: The butt damage from the Harricana circ. saw head is less than for most other "non-shear" felling heads, according to a butt damage study of 16 different felling machines by FERIC's western division. The study was carried out in the B.C. Interior during the winter of 1982-1983 [8]. The main results of that study are presented in Appendix A. The main reason for the low level of butt damage (covered in FERIC's patent application) with the Harricana circ. saw is that the tree is grabbed by the arms after it is severed. In this respect it is similar to the Koehring disc saw, which also causes virtually no butt damage. Most other "non-shear" felling heads (e.g. Denis SJ-24, Lokomo cone saw, Drott auger, Kockums chain saw) require that the tree be firmly grabbed prior to cutting; this often puts bending forces on the tree which results in butt splitting during cutting. Bending the tree during cutting to "open the kerf" can also contribute to the splitting problem on some of these heads.

Fig. 11 illustrates how tree splitting damage can be caused by the Harricana saw head. The operator must align the head with the leaning tree to avoid this problem. Fig. 9 shows that the Harricana circ. saw does not bind even if the kerf closes, as on a large tree. The butt plate not the saw blade, supports the tree weight.

DENIS SJ-24 TWIN SAW

The Denis SJ-24 felling head was invented by Mr. Jean Denis of Équipement Denis Ltée in early 1982. A Canadian patent (1,135,599) on the Denis felling concept was issued in Nov. 1982. The first prototype unit worked fairly well, not withstanding some problems with the saw and teeth design. By mid-1982 several early production units had been sold; these were mounted on excavator-type tracked carriers. At the end of 1982 there were a total of 6 Denis heads in use in British Columbia, northern Ontario and Michigan. These early units required improvements for acceptable performance; the improvements were made by Équipement Denis as part of their product improvement program.

The Denis head features sliding twin circular saws and uses a two-step duty cycle (like the Harricana circular saw) where the head is first placed on the ground in front of the tree to be felled. Unlike the Harricana, the Denis must clamp the grab arm on the tree prior to severing it. This is necessary because there is no butt plate to support the tree during cutting as with the Harricana and Koehring heads.

The Denis head requires 2.8 L/sec (45 GPM) @ 17,000 kPa (2500 p.s.i.) for the twin saw motors when cutting a tree. In addition it usually requires about 90 L/min (20 GPM) to feed the saw forward. With the Denis the saws accelerate from 0 to 2000 RPM (full speed) in about 3 seconds.

FERIC has collected less shift-level information on the Denis head as compared to the Harricana and Koehring heads. One study on a Denis/Drott 40, started at Hearst, Ont. in mid-1982, did not provide useful results. A Denis/Timbco 2518 at Iroquois Falls, Ont. had a delayed start-up, thus only 5 months of data were collected by FERIC. This discussion of the Denis head is also based on experience from British Columbia, from reports by Mr. D. Guimier [8] and Mr. B. McMorland [6] and from observations by the author of the Denis/Drott 40 operated by Ambroy Logging at Fort Fraser, B.C. in Oct. 1982.

At the time of writing (Nov. 1983) about 30 Denis heads had been sold. About one half of these units were in British Columbia with the remainder in Ontario, Québec and the north-eastern United States. The Denis head is lighter in weight and requires less hydraulic power than the Harricana or Koehring heads. As a result it can be mounted on a large variety of carriers using standard hydraulics. The list price for a Denis SJ-24 head (f.o.b. Ste Rosalie, Qué.) in Oct. 1983 was:

- basic head $39,500
- optional accumulator 2,500
- optional side tilt 2,500
- installation $1000-$2000, depending on carrier.

Technical specifications are provided in Appendix D.

ABITIBI-PRICE, IROQUOIS FALLS, ONT.

A Denis SJ-24 felling head, mounted on a leased Timbco 2518 tracked carrier on a Cat 235 undercarriage was operated by Abitibi-Price near Iroquois Falls, Ont. starting in mid-April 1983. Abitibi's earlier experience with the Harricana circ. saw/Timbco (see p. 22) had indicated that a lighter felling head was required for the Timbco carrier. Thus a second Timbco, this time with a (lighter) Denis felling head was acquired. FERIC's data collection started with the introduction of this unit to Abitibi's operation and ended 5 months later. The Denis/Timbco was plagued with high repair downtime levels (see Table 4), most of which was related to the Denis head and its hydraulic system. In Dec. 1983, Abitibi-Price replaced the Denis head with a new (lighter) "standard" version of the Harricana saw head.

The Denis/Timbco was operated in the same cut areas as the Harricana/Timbco, first at Camp 40 (about 40 km north of Timmins) and later 30 km north of Smooth Rock Falls. The stands consisted of even-age black spruce averaging .119 m^3 per merchantable tree. The terrain was flat with no rocks and was classified as 4.1.1 [4]. The Denis/Timbco was operated on a 2-shift per day basis, 5 days per week. Operators were paid on an hourly basis with no bonus provision.

Production: The Denis/Timbco at Abitibi-Price averaged 112 trees/PMH, or 13.3 m^3/PMH, based on an average tree size of .119 m^3.

Repairs: The repair level on the Denis felling head on the Timbco 2518 at Abitibi-Price at Iroquois Falls was high.

The main problem with the Denis head (which occurred on a daily basis from start-up in mid-April to Sept. 1983, when it was corrected) was *saw binding and stalling*. During this period the end of the sliding track was broken and repaired several times; also the saw motors, bearings, saw blades and the protective steel plate under the saws required repairs or replacement several times. Abitibi-Price personnel stated that it was very difficult to tell why the saws were binding. On about 1 in 10 trees saw binding and stalling occurred. When it occurred the operator had to bend the tree forward, retract and restart the saws and then re-insert them. But bending the tree forward also placed unwanted bending stresses on the saw blades bearings and slide assembly. Overheating of the hydraulic oil and resulting O-ring deterioration and pressure losses may well have been important factors in the saw binding problems.

Initially, the local Timbco dealer stated that binding resulted from the operator not providing enough upward lift on the tree. However this change in operating technique did not correct the problem. On Aug. 10 a locking valve (check valve) was installed by the cab tilt cylinder (by the dealer) to correct suspected internal leakage because it could have caused boom movement and resulting saw binding. However this change also did not correct the saw binding problem. On Sept. 14, 1983 a Denis mechanic (from Ste Rosalie, Qué.) finally corrected the problem by using a pressure guage to check the flows and to provide the correct flows and pressures. During the one month period following this change the saws worked well. However, in late October saw stalling and binding problems were again evident. There was insufficient hydraulic power. Undoubtedly the soft ground (black spruce swamp) also contributed to the saw binding problem because of machine sinkage during felling. When a tree was fully severed the "holding wood" no longer held the tree's weight; thus the boom pushed the saws against the stump causing unwanted torque on the saw blades and saw motor bearings.

Table 13. Shift Level Study Results: Denis SJ-24 on Timbco 2518 Carrier at Abitibi-Price, Iroquois Falls, Ont.

		Apr. 1983 (2nd half)	May	June	July	Aug.	Sept. 1983	Total
Scheduling								
Days Reported	(DY)	10	21	22	20	17	21	111
Scheduled Time	(HR)	178.5	354.5	374.0	340.0	312.5	337.5	1897.0
Out-of-Shift Time	(HR)	-	-	1.0	-	-	-	1.0
Total Time	(HR)	178.5	354.5	375.0	340.0	312.5	337.5	1898.0
Shifts/Day	(SH/DY)	2	2	2	2	2	2	2
Machine								
Repair In-Shift	(HR)	29.5	65.0	37.5	53.0	130.5	59.0	374.5
Repair Out-of-Shift	(HR)	-	-	-	-	-	-	-
Service In-Shift	(HR)	13.0	23.5	18.5	20.5	11.0	19.0	105.5
Service Out-of-Shift	(HR)	-	-	-	-	-	-	-
Operations								
Non-Productive Operating	(HR)	-	-	9.0	4.0	20.0	6.0	39.0
Wait Parts	(HR)	-	13.5	4.5	46.5	22.5	25.0	112.0
Wait Mechanic	(HR)	-	-	1.0	.5	3.0	9.5	14.0
Miscellaneous Delays	(HR)	11.0	3.5	35.0	10.5	20.5	27.0	107.5
Machine and Operations								
PMH In-Shift	(HR)	125.0	249.0	268.5	205.0	105.0	192.0	1144.5
PMH Out-of-Shift	(HR)	-	-	1.0	-	-	-	1.0
CPPA Availability	(%)	76	71	84	65	47	67	68
Mechanical Availability	(%)	75	74	83	74	43	71	70
Utilization	(%)	70	70	72	60	34	57	60
Total Time Utilization	(%)	70	70	72	60	34	57	60
Production								
Total Production	(m^3 (ct))	1503 (531)	3521 (1243)	3543 (1251)	3209 (1133)	1257 (444)	2203 (778)	15,236 (5380)
Trees Harvested	(TR)	12,930	31,335	31,532	23,102	10,685	18,509	128,093
Volume per tree	(m^3 (ft^3))	.116 (4.1)	.112 (4.0)	.112 (4.0)	.138 (4.9)	.118 (4.2)	.119 (4.2)	.119 (4.2)
Trees per PMH	(TR/PMH)	103	126	117	113	102	96	112
Productivity	(m^3/PMH (ct/PMH))	12.0 (4.2)	14.1 (5.0)	13.2 (4.7)	15.7 (5.5)	12.0 (4.2)	11.5 (4.1)	13.3 (4.7)

Table 14. Repair Summary: Denis SJ-24 Felling Head on Timbco Carrier at Abitibi-Price, Iroquois Falls, Ont.

		Repair Time (hrs)							
		Apr. 1982 (2nd half)	May	June	July	Aug.	Sept	Total	Comments
FELLING HEAD REPAIRS									
Structural									
Boom adaptor	1								
Main frame (or post)	2								
Tree support	3								
Pins & bushings	4								
Grab arms (2)	5	1.0						1.0	
Tree accum. arm (optional)	6	3.5	.5					4.0	- weld stopper/repair on accumulator arm, April.
Protective plating (above saws)	7								
Protective plating (below saws)	8			3.0				3.0	- weld crack on lower protective plate (3 hr) June.
U-shaped sliding ass'y									
Sliding mechanism	9		9.0					9.0	- weld brackets on sliding ass'y cyl. (2 x - 9 hr) May.
U-shaped plate	10								
Circular saw assemblies									
Saw mounts	11	1.0	.5					1.5	- tighten saw blade bolts, April.
Shaft & bearings	12		9.0					9.0	- replace shafts and bearings (9 hr) May.
Clear debris from saw(s)	13								
Sharpen saw teeth	14						1.5	1.5	- sharpen saw teeth (2 x) Sept.
Repair/Replace saw(s)	15			1.0	2.0	1.0		4.0	- replace saws (2 x - 2 hr) July.
Other	16		1.0				1.5	2.5	- saw jamming diagnosis (1.5 hr) Sept.
Other	17	1.0						1.0	
Hydraulic/Electrical									
Flexible hoses									
Between boom & head	18	1.5				1.5	4.0	7.0	- replace hoses (4 x - 7 hr) in Sept.
Other	19			0.5		1.0		1.5	
Fittings	20	1.0	.5	3.0		.5	1.5	6.5	- tighten fittings (5 x) June. Tighten/replace fittings (4 x) Sept.
Motor for circular saw	21		4.0	4.5		2.0	3.5	14.0	- replace oil seal on motor (3.5 hr), replace motor (.5 hr) May, repair saw motor (2.5 hr) June, reverse motors (2 hr) June, adjust hydr. pres. for motor (2 hr) July, repair motor (1 hr) Sept.
Cylinders									
Grab arms (2)	22				1.5		6.0	7.5	- replace grab arm cylinder (1.5 hr) July, repair broken pipe for grab arm (6 hr) Sept.
Tree accum. arm (optional)	23		1.0				1.0	2.0	- replace O-ring, May.
Sliding ass'y (2)	24		3.0				2.0	2.0	- repair cyl. on sliding assembly (3 hr) May.
Electr./hydraulic controls									
Saw advance/return	25	3.0	6.5				2.5	12.0	- change switch/replace hose, Apr., repair saw advance/return (6.5 hr), May, change switch, Sept.
Check valves	26		3.0	1.5	1.5	2.0	5.0	13.0	- replace check valve (2 x) June, repair check valve (2 hr) Aug., replace check valves (2 x - 3 hr) in Sept.
Electr./hydraulic valves	27		9.0	4.0				13.0	- replace valves in valve bank (4 x - 9 hr) May, replace saw motor valve (3 hr) June, adjust pressures (Denis mechanic) 8.5 hr - Sept.
Controls (for felling head)	28		1.0					1.0	
Other	29	2.5	1.5					4.0	- weld hydr. pipe, May.
Sub total: Felling head		14.5	49.5	17.5	5.0	8.0	28.5	123.0	
CARRIER REPAIRS									
Power & transmission unit	30	6.0	4.5	14.5	12.0		6.5	43.5	- replace radiator (4 hr) Apr., blocked fuel line (4.5 hr) May, blocked fuel line (4 x - 12.5 hr) June, clean radiator (3 x - 1.5 hr) June, clean radiator (.5 hr) July, repair leaky fuel tank (7 hr) July, remove & weld radiator (4 hr) July, repair cooling on engine (.5 hr) drain fuel tank (2 hr) blocked fuel line (4 x - 4 hr) all in Sept.
Drive system (incl. tracks)	31	2.0	.5					2.5	- work on track guides, Apr.
Hydraulics on boom (only)	32	1.5		.5	25.5		1.0	28.5	- rebuild tilt (crowd) cylinder (25.5 hr) July.
Hydraulics (general)	33	2.0	7.5	3.5		11.0	13.0	37.0	- change valves, Apr., repair hydr. oil cooler (6 hr) May, replace swivel (1.5 hr) May, replace O-ring on main pump (2.5 hr) June, swivel fitting on hydr. pump (1.0 hr) June, replace valve on cab tilt (4 hr) Aug., hydr. pressure adjustments (7 hr) Aug., hydr. oil cooled (5 hr) Sept., pressure adj. (1.5 hr) Sept.
Electrical system	34			1.0		2.5	5.5	9.0	- repair lights, Aug., replace alternator (2 hr) Sept.
Chassis & frame	35					47.5	1.5	49.0	- weld chassis and frame - due to cracks - at dealer in Timmins (47.5 hr) Aug.
Booms	36								
Turntable/swing ass'y	37				10.5	61.5	2.0	74.0	- repair stopper on swing ass'y (8.5 hr - 2 x) July, replace stopper (1 hr) Aug., repair bearing on swing motor (3 hr) Aug., replace swing motor (4 hr) Aug., repair main (crown) gear at dealer in Timmins (53 hr) Aug., replace swing stopper (.5 hr) Sept., replace swing motor hose (4 x - 7.5 hr) Sept.
Other	38	3.5	3.0	.5			1.0	8.0	- weld handles on cab Apr., replace (safety glass) windshield (1 hr) May, repair windshield (.5 hr) June, replace windshield (1 hr) Sept.
Sub total: Carrier		15.0	15.5	20.0	48.0	122.5	30.5	251.5	
TOTAL		29.5	65.0	37.5	53.0	130.5	59.0	374.5	

A major problem with the Denis head (that has also been a problem on other logging operations contacted by FERIC) was the hydraulic/electrical features on the head. These are complex in nature and are difficult to diagnose (to find the cause of a problem) when malfunctions occur, especially for field mechanics unfamiliar with these components. On the Denis head there are 4 hydraulic "blocks", a number of pilot-operated solenoid valves, many check valves and several "accessory" valves (see p. 43). To find the cause of a malfunctioning part (e.g. grab arms) it is necessary to inspect a series of parts; this can take several hours especially in adverse weather conditions.

NOTE: In Dec. 1983, FERIC discussed with Mr. J. Veillieux (logging foreman) of United Sawmill, Hearst, Ont. their experience with five Denis heads obtained during Aug. 1982 to Nov. 1983. One of these heads was the subject of a recent paper by R. Fontaine [9]. Mr. Veillieux noted that there had been a good level of co-operation between Équipement Denis Ltée and United Sawmill to carry out necessary improvements, especially to their first unit and that the lower purchase price had been an important factor in choosing the Denis heads. Production results with the Denis head had been "mixed" mainly because diagnosis of malfunctioning parts often proved difficult and time-consuming. Saw motor bearing problems had also occurred. Mr. Veilleux noted that the Denis head would benefit from a simplified hydraulic/electrical system. NOTE: Équipement Denis have indicated to FERIC that this may be done on future versions built.

GENERAL COMMENTS

Production: During FERIC's 5-month study the Denis/Timbco produced 112 trees/PMH or 13.3 m^3/PMH, based on an average tree size of .119 m^3. The low productivity during the first month of the study was attributed to operator training.

NOTE: The long term productivity of the Harricana circ. saw/Timbco (earlier) at the same operation was 102 trees/PMH or 15.3 m^3 based on an average tree size of .150 m^3 (see Table 8). Although the trees/PMH was lower for the Harricana/Timbco, the production supervisors at Abitibi-Price stated that the Harricana should have produced more than the Denis *but* was handicapped by:

1. Improper hydraulic hook-up initially. The operator spent time waiting for the saw RPM to build up.

2. The boom could not lift one (or more) trees at full boom extension.

3. Operator turnover. The Harricana controls are somewhat more difficult than the Denis controls; thus operator turnover and training was a factor.

A productivity comparison at United Sawmill, Hearst, Ontario provides a more useful comparison between the Harricana and Denis heads. There a Denis/Drott 40 and a Harricana/JD693 (see Tables 6 and 7) operated side-by-side for over 1 year. The logging foreman at United Sawmill stated that (based on their own data collection) the productivity of the Harricana/JD693 *on a PMH basis* was consistently 10% higher than the Denis/Drott 40.

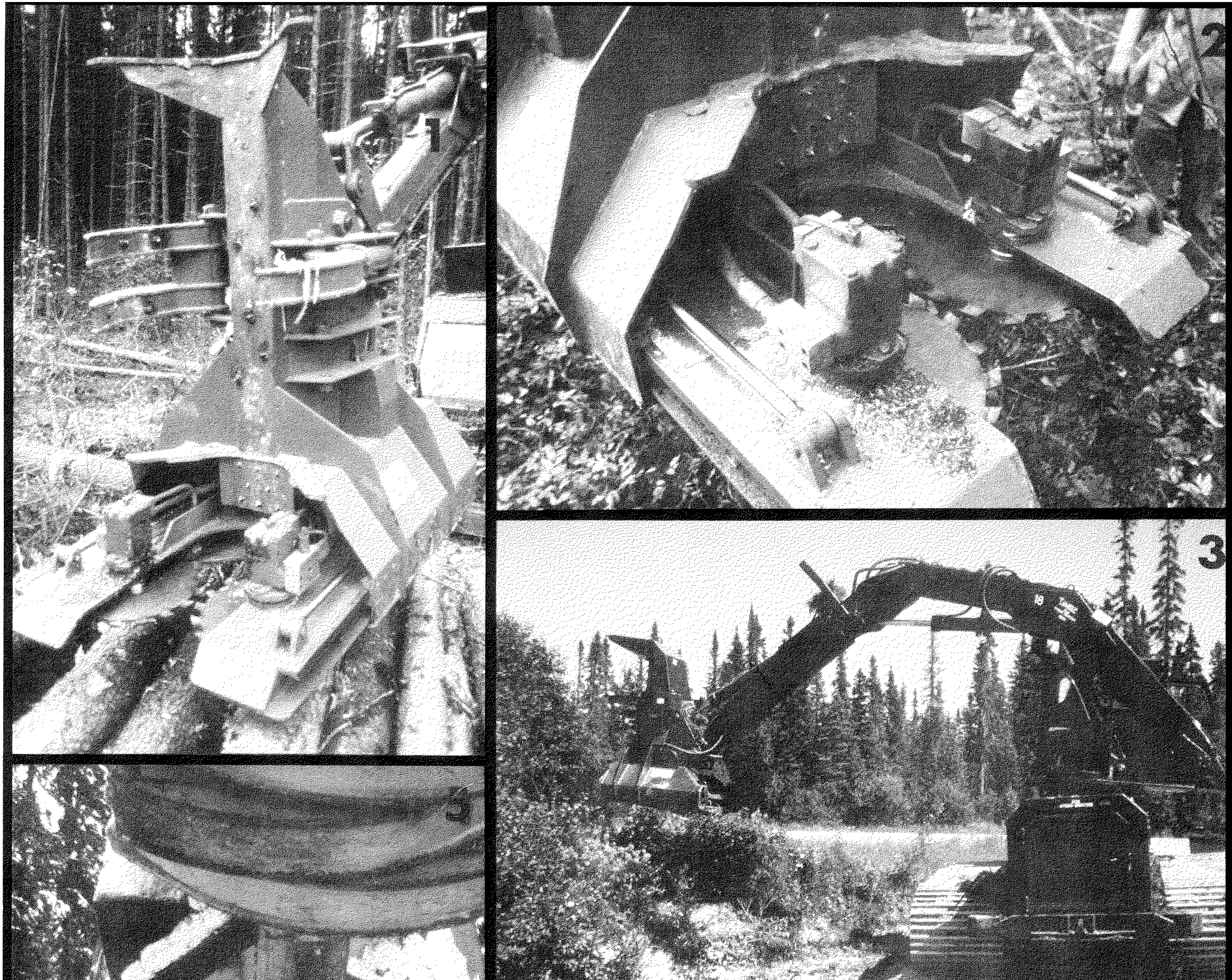


Fig. 12. Denis SJ-24 twin saw head; 1 & 2: on a Drott 40 at Fort Fraser, B.C. (Oct. 1982). Flame-cut (one-piece) blades were used; 3 & 4: Denis head on Timbco 2518 carrier at Abitibi Price, Iroquois Falls, Ont.; 5: Denis head with saw feed extended, on Drott 40 at United Sawmills, Hearst, Ont.

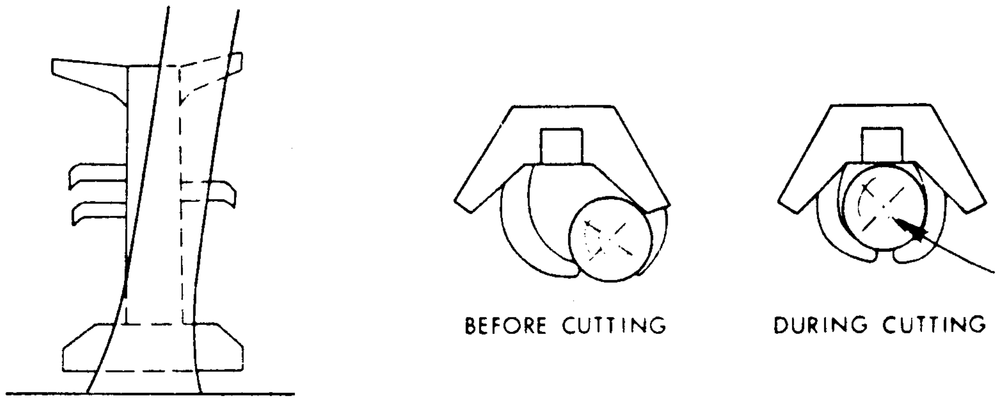


Fig. 13. Denis head. Fixed horns at the top of the mast and lack of side tilt created cutting problems resulting in butt damage on an early version of the Denis; during Guimier study in Feb. 1982 [8]. Side tilt on the head is now available as an option. NOTE: For operating on uneven terrain, tilt on the turntable (as well as on the head) is desirable. A level turntable and cab permits trees to be swung uphill more easily.

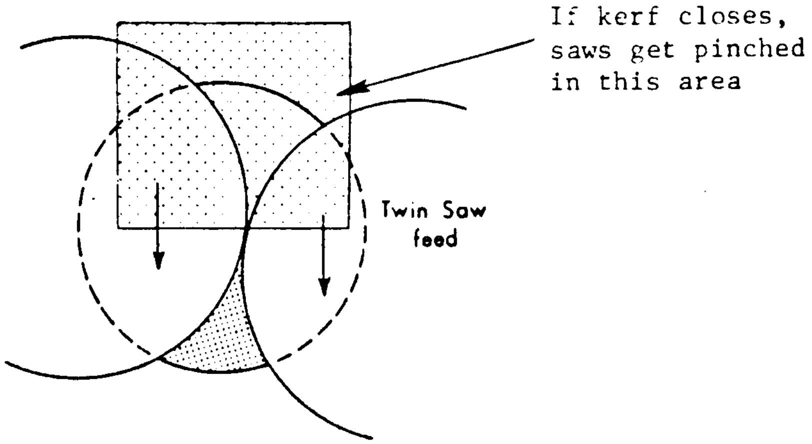


Fig. 14. Back of Denis saws get pinched if kerf closes.

For the relatively small trees at United Sawmill the Harricana head was more productive than the Denis. This may not be true when felling larger trees (e.g. 40-50 cm at stump) since there may be a delay while waiting for the Harricana saw's RPM to return to normal. Thus the Denis (no wait time) may be able to cut the same number of trees/PMH as the Harricana in these (large tree) conditions.

Saw Blades: Équipement Denis Ltée have tested different types of saw blades with variable results. The Simons saws (a, b and c) listed below are .95 cm (3/8 in) thick with a 1.61 cm (5/8 in) kerf.

(a) One-piece blade, by Simons. A set of two blades costs $550.
(b) Multi-piece standard insert by Simons. The teeth are replaceable and are spring-loaded. A set of two blades costs $650. Replacement teeth cost $2 each and can be replaced without removing the blade.
(c) Multi-piece, carbide insert by Simons. The replaceable carbide teeth are riveted to the blade which must first be removed from the head. Cost for a two blade set is $800; replacement teeth cost $6 each.
(d) Flame-cut saw blades made by Équipement Denis from alloy steel. These blades are 1.27-cm (½ in) thick (see Fig. 12).

At Abitibi-Price, several different types were used. The flame-cut saw blades were favoured because they were thicker and less likely to be bent if the operator made a mistake or if saw binding occurred. At United Sawmill, Hearst, Ont. all the saw blade types mentioned above were used. The Simons one-piece blades (a) were used with good results but were sometimes bent. Overall, for United's conditions, flame-cut saw blades (d) were considered the best.

Flame-cut saw blades for the Denis head must be sharpened frequently especially when cutting larger trees. They are not bent as easily, if for example a raised tree slips through the grab arms and falls onto the saws, or if there is boom movement during cutting. For operator training and for uneven ground conditions the flame-cut blades have a definite advantage. NOTE: In the B.C. Interior, locally-made flame-cut blades with replaceable carbide tips are also in use.

For operation in rocky or boulder-strewn terrain, none of the Simons saws (a, b and c) were considered suitable. For the flame-cut blades the results were considerably better, depending to a large extent on the operator. With flame-cut blades, when making contact with rocks the teeth are dulled but can usually be sharpened or built up again with a welding technique. Damaged teeth can greatly affect the cutting ability of a saw blade. More power is required for cutting. Since Denis blades have only a fraction of the *flywheel effect* obtained with the heavier Harricana and Koehring blades, the effect of dull teeth is much greater.

The deflection caused by a load on the edge of a Harricana blade (dia. 137 cm) is 5 to 10 times as high as when the same load is applied to the edge of a Denis blade (dia. 61 cm) of similar thickness. This makes the Denis blades more rigid during operation. However the Harricana has a butt support plate that usually takes most of the load; the Denis does not and thus the force is transferred to the Denis saw motor bearing. Saw motor bearing problems were reported on the Denis units at both Abitibi-Price and United Sawmill.

The quality (smoothness) of the cut produced by the Denis is generally much superior to that produced by the Harricana and Koehring saws. The frayed cut produced by a Harricana or Koehring head may create difficulties for scaling or sorting purposes because it may be difficult to determine the extent of butt rot. It was observed that the Simons saws (a, b and c) produced a smoother cut than the flame-cut blades (d) on the Denis.

One problem peculiar to the Denis is that after the blades have been sharpened a number of times they become smaller in diameter and a thin hinge of wood is left between the two saws, resulting in wood pull out. This problem was reported at both Abitibi-Price and United Sawmill. A greater offset for the two saws or an angled slot mounting for one saw motor should solve this problem.

Hydraulics: The Denis head requires a *smaller hydraulic flow* (see p. 35) as compared to the Koehring and Harricana heads. This, plus its lighter weight (approx. 1800 kg) means that the Denis can be installed on nearly all sizes of excavator-type carriers without changes to their *standard* hydraulic systems. Also, since the tree is firmly grabbed prior to severing, the hydraulic flow used for the saw does not interfere with grab arm functioning. (Proper grab arm functioning may be a problem with Koehring and Harricana heads if a *standard* hydraulic system on a carrier is used.)

The Denis is considerably more complex as compared to the Harricana and Koehring felling heads because it has many electrical/hydraulic components. Examples of these components are: the automatic locking device on the grab arms during sawing, the solenoid valves, the rated feed flow device which senses RPM slowdown of saws and thus reduces the feed speed, the saw feed feature which retracts the saws automatically if the operator releases the button and the saw feed feature that prevents them from being used if the grab arms are not closed. These features may cause diagnostic and repair problems for field mechanics not familiar with these components. NOTE: At United Sawmill during the summer of 1983, malfunctioning check valves on the hydraulics of the Denis heads caused considerable problems.

Overheating: The Denis/Timbco had some problems with overheating of the hydraulic oil but it was not clear how much downtime resulted from the pressure losses caused by overheating. Overheating of the engine was a significant problem on the Denis/Timbco; the radiator screens had to be cleaned frequently. The low and enclosed position of the engine on the Timbco (below the turntable) makes it more difficult to provide adequate cooling capacity for both engine and hydraulic components. The temperature in the cab was too high (usually over 30°C) even with the door open. The inadequate cooling capacity of the engine, and hydraulic system plus the high ambient temperatures and small cab size are limitations that should be addressed by the manufacturer. Frame cracking problems (that occurred earlier on the Harricana Timbco - see p. 22) also occurred on the Denis/Timbco, but to a much lesser degree.

Operational Aspects: The Denis head is more simple to operate than a Harricana head because fewer control buttons are required. After an operator is fully trained this advantage disappears. While the Denis head is more simple to operate, it must be operated more carefully to avoid butt splitting on trees and to prevent damage to the saw blades and saw motor bearings. With the Harricana, butt splitting will seldom be a problem even with a careless operator because the tree is grabbed after it is cut, not before. Also, its butt plate helps to protect the saw blade and saw bearing assembly.

The visibility of the tree being cut is better on the Denis head than on the Harricana. Also, the base area (footprint) of the Denis is much smaller which makes it easier to position the Denis on a tree. When working in one metre or more of snow both felling heads worked well. With the Denis head the snow is usually blown downwards out of the open back of the felling head using a deflector.

High stumps can be a problem with the Denis head. The wide arms (of the U-shaped plate on which the saw motors are mounted) can be difficult to insert between two trees growing close together. Also if two trees are close together the bottom of the Denis saw head will rest on the first stump while cutting the second one. The second stump will be 20 cm higher than the first. For hardwood clumps where several stems grow from one point it may be difficult to use the Denis head.

Butt Damage: During the winter of 1982-1983, D. Guimier of FERIC's western division carried out butt damage studies on various feller bunchers used in the B.C. Interior [8]. The study results (presented in Appendix A) indicate that 40% of the trees felled by the Denis head exhibited some butt splitting damage; this was higher than for most other "non-shear"heads. It was observed that on larger trees, the saws on the Denis often did not cut through in one motion. The saws were then retracted and re-inserted, with the operator stressing the tree to keep the saw kerf open. The uneven terrain and the lack of a side tilt device also had some effect on these results. However, the discussion below, based on D. Guimier's report [8] indicates that the Denis has some inherent design features that tend to cause butt splitting damage, particularly on larger trees.

NOTE: In mid-1983 Équipement Denis Ltée provided their newly-built heads with a rated feed flow device which is designed to reduce butt splitting damage. Also the base of the saw head was modified to conform more closely with tree butt flare. The rated feed flow device is a counterbalance valve that senses RPM slowdown of the saws; it then causes the feed cylinders to feed more slowly. These changes should help to reduce the level of butt splitting with the Denis, particularly if the saws are kept sharp and the operator is careful not to pre-stress the tree.

Positioning the Head on the Tree: To avoid butt damage, positioning should not bend or deflect the tree. For feller bunchers like the Denis it is critical that the head be aligned to the tree. If head positioning is not perfect bending and shear pre-stresses, resulting in damage, will be applied when the grab arms are closed. However, to obtain acceptable production levels very exact alignment of the head and tree is not achievable and operators have to compromise between quality and production. Denis head operators observed by FERIC in Ontario stated that they could not afford the time to be careful with every tree. For example, the cab tilt feature on the Drott 40 carrier was not always used. Also, if a tree was leaning the wrong way or if operating on uneven terrain, a tree might have to be approached from the side (another direction) to avoid pre-stresses. In reality, this was seldom done because of the extra time required.

Cutting: The Denis creates a triangle-shaped holding wood as the two saws are pushed into the tree; splitting can occur from stresses in almost any direction.

Kerf Opening: Most of the butt splitting damage on "non-shear" felling heads (chain saws, augers, etc.) results from pushing or pulling the tree during cutting to keep the kerf open so that the cutting tool does not bind. With the Denis head, the operators observed by FERIC usually put an upward lift on all trees over 20 cm. In addition, for trees over 30 cm they normally bent the trees forward during cutting to open the kerf. Fig. 14 shows that the back of the saw blades on the Denis head can easily be pinched when the kerf closes. Increasing the kerf by using larger saw teeth will not solve the binding problem at the back of the saw blades.

Supporting the Tree Weight: The weight of the tree is supported by the holding wood until the tree is completely cut. It then tends to crush the cutting tool between the butt log and the stump. The Denis head relies on the grab arms to support the tree weight. Spikes added to the grab arms and tower are used to prevent the tree from sliding down. This need to grab the tree results in stresses; therefore butt damage can result.

BOREAL DD-20 DOUBLE-DECK SAW

The Boreal saw concept was invented by Mr. André Larose of Équipement Hydraulique Boreal, Macamic, Québec after he observed a Koehring disc saw head in operation. Subsequently, Larose decided to develop a lighter, narrower felling head using the "double-deck" principle. The Boreal felling head is protected by Canadian patent 1,140,029, issued in 1983.

The first prototype was built in early 1983 and was tested near Iroquois Falls, Ont. on a Liebherr 925 carrier supplied by Abitibi-Price Inc. This unit was observed by FERIC in operation in early March. This first prototype was capable of cutting trees up to 30 cm, but was limited to one tree per felling cycle since there was no tree accumulator; also there were many design problems to be resolved.

A second felling head was built. It was mounted on a JD693 tracked carrier and was tested in regular production at Clouthier Bros., near Strickland, Ont. during the summer of 1983. The design problems that were evident in the first prototype were gradually resolved by tackling one problem at a time, making the necessary changes, followed by more testing. FERIC observed this second unit operating near Strickland in July 1983.

A third version prototype having a tree accumulator was built in August, 1983 and exhibited at the F.I.E.E. in Ottawa in September. After the F.I.E.E., this same unit was mounted on the JD693 at Clouthier Bros. for testing in regular production.

> NOTE: A Boreal unit was also tested at 100 Mile House, B.C. This unit, mounted on a Drott 40, required stronger grab arm brackets for the larger, longer trees of B.C. and a side-tilt (which is available) mechanism for working on slopes. Also angled prongs were added to the base of the head to secure it onto the stump during felling. These stump grabbers prevent movement of the head during and immediately after cutting; they help to prevent damage to the saws, bearings and slide mechanism. Boreal Hydraulics plan to resume their testing in B.C. Interior conditions after these modifications are completed.

The Boreal head has several potential advantages, as compared to other non-shear felling heads:

1. It is light weight and narrow. Although the prototype versions have weighed up to 1600 kg the newest version planned by the manufacturer is expected to weigh only 1100 kg. The version studied by FERIC was 75 cm wide, thus offering good visibility for the operator.
2. The power requirement is relatively low and can be supplied by most carriers. It requires a total flow of 4.4 L/sec (70 GPM) @ 17,000 kPa (2500 p.s.i.).
3. The saw is turned off when not cutting a tree. As a result of the reduced power demand fuel consumption is expected to be lower.

To operate the Boreal head the operator closes the main grab arms around a tree, then lifts up on the boom (to prevent saw binding) prior to advancing the saw feed (a thumb switch). Saw rotation is instantaneous and is activated with a floor pedal. It is activated at the same time as the saw feed. When the tree is fully severed the saw feed return is activated; this automatically shuts off the saw rotation.

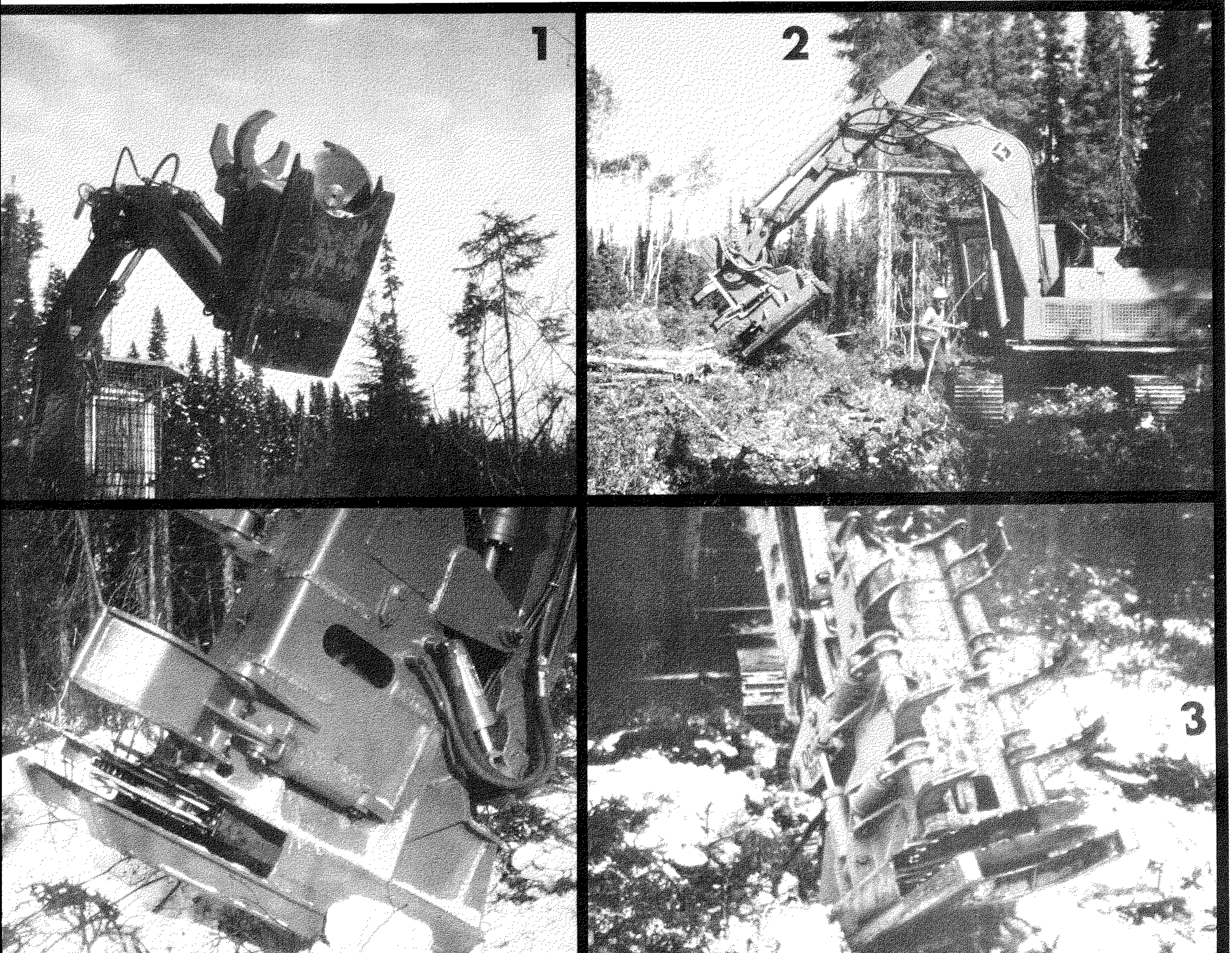


Fig. 15. Boreal DD-20 double-deck saw; 1 & 2: on JD693 at Clouthier Bros., Strickland, Ont. (July 1983); 3: new version with tree accumulator arms at Strickland, Ont. (Nov. 1983); 4 & 5: same version as (3) near to and at F.I.E.E.,Ottawa (Sept. 1983); 6: prototype version tested near Iroquois Falls, Ont. (March 1983).

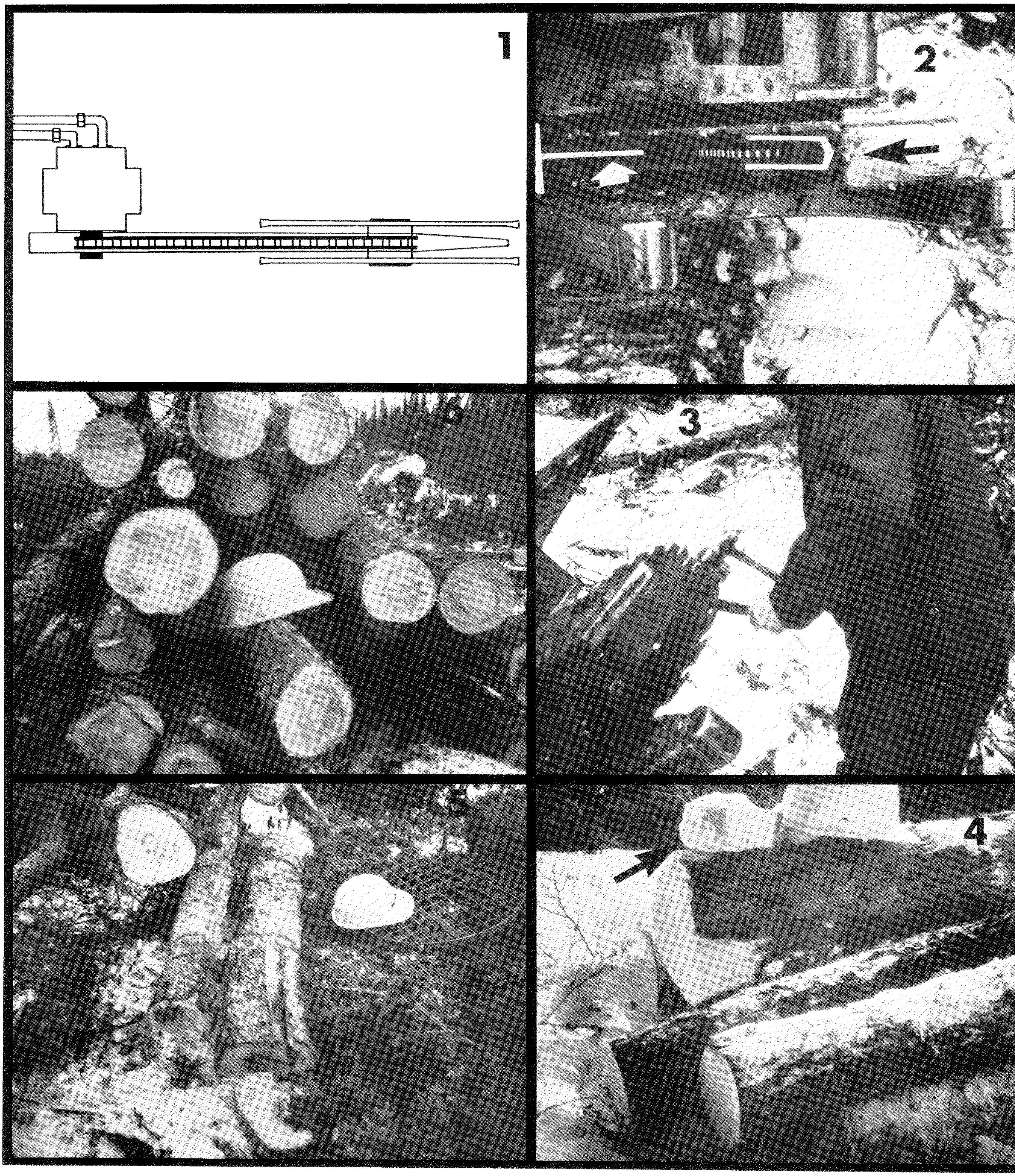


Fig. 16. Boreal DD-20 double-deck saw: 1: schematic drawing showing the saw motor, chain drive, saw assembly and splitting wedge (between the saws); 2, 3, 4, 5 & 6: Boreal head and felled trees at Strickland, Ont. (Nov. 1983); 2: note the narrow fixed arms which made it easy to place the head between trees growing close together, the splitting wedge (see arrow) and the insert plate (see arrow) between the two saws; 3: replacing teeth bits on the saw teeth is a relatively simple procedure; 4: the kerf of the Boreal head is 10 cm; it includes a 6-cm disc from between the saws (see arrow); FERIC's study found that only 8% of the trees sampled showed any butt splitting damage; the damage was usually confined to small diameter trees.

The basic price of the Boreal DD-20 saw head in Nov. 1983 was $39,000 (f.o.b. Macamic, Qué.) including the side tilt and tree accumulator feature. Replacement saws (71 cm in diam - supplied by Simons) were reported to cost about $700 per pair. Inserted tooth bits for the replaceable teeth cost from $1 to $2 each. Technical specifications for the unit shown at the F.I.E.E. (the same unit studied by FERIC) are provided in Appendix E. Boreal Hydraulics plan to make additional changes to future units. These changes are described in the following text.

CLOUTHIER BROS., STRICKLAND, ONT.

A Boreal DD-20 saw head mounted on a used JD693 tracked carrier was studied by FERIC in mid-November 1983, at Clouthier Bros.' logging operation near Strickland, Ont. This (third version) Boreal head had been in use for 6 weeks on a regular, 2-shift-per-day basis, 5 days per week, with good results. One of the two operators was observed by FERIC. He carried out all the service and most of the repairs, if required, and was paid on an hourly basis with no bonus. He was considered by FERIC to be an excellent, conscientious operator. The operating conditions were very similar to those recorded for other saw heads in the Clay Belt in this report; the operating conditions are summarized in Table 15.

Production: Table 16 indicates that the average productivity during FERIC's 2.7 hour study was 143 trees/PMH, or 22.7 m^3, based on an average tree size of .158 m^3. These results indicate that the Boreal head worked well and that its accumulating arms functioned properly. The splitting or clearing action of the steel wedge (located between the two saws) also functioned well. It functioned properly on all sizes of trees (up to approx. 40 cm stump diameter) encountered.

Most of the delays (5.3% of total time) recorded in Table 16 resulted from small fragments of wood becoming jammed between the insert plate (see Fig. 15) and the lower saw blade. When a piece of wood became jammed the saw produced a different noise (whine) and the operator would stop felling, dismount from the cab and remove the wood fragment with a hooked rod kept in the cab for that purpose. According to the operator, failure to remove these wood pieces could result in a warped saw blade because of localized overheating caused by friction. A warped saw blade would have to be removed, replaced and later re-tempered at a sawmill filing shop. NOTE: Boreal Hydraulics hope to reduce this potential problem on future units.

Repairs: The Boreal head is new. Since further changes are planned (see later text) FERIC has not (to date) initiated a long-term study of production and mechanical reliability, as done for several other heads mentioned in this report. In this section the comments are based on FERIC's observations of the Boreal head in Nov. 1983, and on discussions with operating personnel at Clouthier Bros. The section following it outlines the earlier experience obtained with Boreal prototypes.

Table 15. Stand and Terrain Factors.

	Boreal DD-20 Saw Head/JD693 at Clouthier Bros., Strickland, Ont.
Location	10 km north of Strickland, Ont.
Study date	November 14, 1983
Stand type	clearcutting
Species	black spruce 100%
Trees per hectare	900 (estimated)
Volume per tree	.158 m^3 (5.6 ft^3)
Terrain	lowland, classified as 4.1.1 [4]

Table 16. Production Summary

	Boreal DD-20 Saw Head/JD693 at Clouthier Bros., Strickland, Ont.	
	time per tree, cmin	%
Move empty	5.6	13.4
Felling cycle	31.2	74.5
Move between trees	0.8	2.0
Brushing	2.0	4.8
Delays	2.2	5.3
Total time per tree	41.8	100%
Duration of study, hr	2.69 PMH	
Total trees harvested	386	
Total cycles	204	
Cycles/PMH	76	
Trees/cycle	1.89	
Trees/PMH	143	
Volume/PMH	22.7 m^3	

The operator of the Boreal head noted that the only downtime with the new Boreal head (during the previous 6 weeks) was caused by (operator) error. He had pushed the boom against the ground to obtain extra traction for the carrier. However, since the saws were not fully retracted, the bottom saw blade was bent and needed to be replaced. Several months earlier (on another Boreal prototype) he had made the same mistake two times. In each case the bent saws were removed, replaced and later straightened in a sawmill filing shop. NOTE: Earlier in 1983, Boreal Hydraulics provided a locking device on their head which neutralized the boom controls until they were returned to their rest position. Although this device was removed because it reduced productivity (the boom could not be raised immediately after cutting - until the saws were returned) this feature should be available to those Boreal owners who want to protect their saw blades, bearings and slide assembly from operator error. A manual over-ride should be provided in case the tree inadvertantly forces down on the saws and causes saw binding, preventing the saws from being returned.

Repairs/Modifications Required on Earlier Prototypes: A discussion of the earlier problems should provide some insights into the use of the Boreal head.

Clearing the wood disc: On earlier prototypes considerable problems were encountered in splitting and/or discarding the wood disc (approx. 6 cm thick) cut between the saws. The hydraulic feed cylinder often proved incapable of splitting the discs of trees over 30 cm at the stump. Several approaches were used. Double hydraulic feed cylinders to provide more splitting force were tested, but were later rejected. The angles of the splitting wedge were changed. The most useful modification was the change from 61 cm to 71 cm diameter (Simons) saws. This extra cutting ability permitted "holding edges" of wood and root flares to be cut; their complete severing reduced the need for more power on the disc splitter. A possible disadvantage is that the larger saw is more exposed to damage, but this has not proved a problem to date.

The sealed roller bearings between the saws sometimes overheated and caused problems on earlier Boreal prototypes. Overheated bearings have resulted from excessive saw RPM, caused by excessive hydraulic pressures; this problem has since been corrected (normal saw RPM is 2000). Insufficient machining tolerances (e.g. .005 in) on the roller bearing mounts was another cause of bearing failure; a better fabricating procedure should correct this on future units (as noted earlier, there were no bearing problems reported on the Boreal head studied by FERIC after 6 weeks of use). NOTE: The limited space available between the two Boreal saws makes it impossible to install larger bearings. As a result the "shock-load" (that may result when a tree accidently slips through the grab arms onto the saw, or when the saws are dropped onto a stump) may cause damage to the bearings. FERIC considers the bearing life to be a critical factor when using the Boreal head. A careful operator will greatly enhance the life of the saw bearings.

The roller chain: The Boreal felling head is the only felling head (in this report) that utilizes an (exposed) chain drive for the saws. To date the chain drive has not caused any problems. However, if foreign objects such as stones or metal enter the chain drive area, a problem could result. On the Clouthier Bros. unit a tightening device for the roller chain is provided; this is necessary to maintain chain tension when wear occurs. The sealed, lubricated DAIDO roller chain used by Boreal Hydraulics should last much longer than standard roller chain. Only long-term operating experience will provide useful information on roller chain and the drive component life.

Operation of the saw: On the earlier Boreal prototypes the saws were turning all the time while the machine was felling. The saws turned on the way back to their rest position and while in their rest position. On the return (since the "holding hinge" of wood was cut) saw binding often occurred because the weight of the tree (and boom) was pushing down on the saws. Now the Boreal head is designed as follows: when the saws have completed their cut and the operator pushes the saw return switch the power to the saws (rotation) is automatically cut off. This reduces high loads on the bearings.

Grab arms and tree accumulator arms: Earlier Boreal prototypes were not equipped with tree accumulator arms. The resulting lower productivity (a major drawback as compared to competing heads) has been eliminated by adding tree accumulator arms. The main grab arms on the Boreal head were (and still are) located at the base of the felling head. Although this location may be useful to prevent long butt splits, it may not provide adequate grip when holding onto (or swinging) large trees, especially on windy days, etc.

Planned Modifications for Future Boreal Heads: The manufacturer has plans to make several changes to the Boreal head observed by FERIC.

1. The weight will be reduced from 1600 to 1100 kg. This will be done by building the head almost entirely from CHT steel, which has 3 times the strength of regular steel. Thinner steel components will provide more strength than on the present unit.

2. Boreal Hydraulics plan to build and install a hydraulic manifold using a pilot pressure system and electrical controls. The 4.4 L/min (70 GPM) flow from the pumps will require two hoses to the head (one pressure and one return) plus an electrical cable. The flow will be split in the manifold 1.0 L/min (15 GPM) to the saw feed; 3.5 L/min (55 GPM) to the saw motor). A directional valve (operated by a solenoid valve) will permit the 3.5 L/min (55 GPM) flow to the saw motor to be directed to the tilt, grab arms and accumulator arms, each of which is controlled by a solenoid valve. The manifold will also include a pressure compensating valve to provide a more consistent saw feed speed. NOTE: The above manifold and its attached components will provide the Boreal head with a compact hydraulic control valve package. Diagnosis and repairs (by unit replacement) will be made easier. Also, the internal hydraulic routing will reduce maintenance on hoses, fittings, etc.

3. The accumulator arms will be re-designed to accommodate crooked or tilted trees more easily. The outer sections will be thinner so that a second or third tree placed against the closed grab arms will not be bent as much.

4. A "float" mechanism may be provided for the head. After a tree is grabbed and prior to advancing the saws the tilt, grab and accumulator arms will (for .5 sec) go into a "float" position. This would permit the head to align with the tree (in all directions) and should reduce butt splitting damage caused by bending the tree during felling. The technical aspects of the "float" function requires further study by Boreal Hydraulics before this feature can be tested.

Butt Damage: The Boreal felling head can significantly reduce butt splitting damage as compared to shears. The degree of butt splitting that can be expected will be highly dependent on the operator. For example, a careless operator who does not align the head carefully on each tree will cause more butt damage than a careful operator.

FERIC conducted a butt damage study of 78 sample trees at Clouthier Bros. at Strickland, Ont. in Nov. 1983. Less than 8% of the trees showed evidence of butt splitting damage. The damage was confined to small diameter trees (under 20 cm d.b.h.). It is likely that some of the trees that were damaged were second or third trees that were bent during the accumulation phase, or while severing occurred. The operator observed by FERIC was probably more careful than most. Higher levels of splitting damage could easily result if an operator was less careful.

The Boreal head produces a smooth cut surface similar to the Denis saw head. This smooth surface may be an important advantage vis-à-vis the Lokomo, Koehring and Harricana heads which produce rough, frayed surfaces that make it difficult to determine the presence of butt rot.

The kerf of the Boreal head (10 cm) is much larger than for the other heads discussed in this report since it includes a 6-cm thick wood disc from between the saws. This compares to about 4 cm for the Koehring and Harricana saws and less than 2 cm for the Denis and Lokomo units. The greater amount of wood wasted during felling is certainly a factor that needs to be considered by potential Boreal users. Some potential users have pointed out that they like the higher cut on the tree produced by the Boreal because it reduces butt flare problems for the mills. However, a butt end reducer (e.g. Bruks Butt End Reducer - supplied by B.D.R. Machinery of Mississauga, Ont.) installed at the mill appears to be a much better solution to reduce butt flare problems.

GENERAL COMMENTS

During FERIC's study at Strickland, Ont. the Boreal head performed well. The productivity of this unit (equipped with tree accumulator arms) was similar to that observed for the Denis and Lokomo felling heads. The Boreal head studied by FERIC was a pre-production unit. The manufacturer plans several more modifications; the weight will be reduced from 1600 to 1100 kg by using (thinner) CHT steel, a hydraulic manifold will be installed, and the tree accumulator arms will be re-designed. Because of the many changes made to the Boreal head during the past 10 months it is not possible at this time to make a comprehensive assessment of the unit's mechanical reliability.

On the positive side: The Boreal head is light-weight and narrow and offers excellent visibility for the operator. There are very few protruding or un-protected parts on the sides of the head. The hoses for the cylinders are all routed to the inside of the head to provide maximum protection for these components. The light weight of the Boreal head should permit the use of smaller carriers and/or reduced wear on the boom, boom pins and turntable components, as compared to heavier felling heads. The light weight of the Boreal head was considered important at Clouthier Bros. They (in Aug. and Sept. 1983) had tried a new version of Harricana circ. saw head on the same JD693 on which the Boreal head was mounted, but discovered that the 2230 kg Harricana head was too heavy for their "wet-ground" conditions. The felling head (especially when it was extended) caused too much track sinkage on the weighted end of the machine. On the Boreal head the power requirement is relatively low. Since the saws are turned off immediately following the cutting action less power is required from the engine. Reduced fuel consumption is a positive benefit.

Butt damage is considerably reduced as compared to shears. However with the Boreal head, the amount of butt damage will depend greatly on the how carefully the operator aligns the head on each tree. A careless operator can cause much more damage than a careful one.

On the negative side: the Boreal head is a recent entry into the "non-shear" felling head market. It has not been tested as long, or as extensively as some of the other "non-shear" felling heads discussed in this report. For the Boreal head, several major modifications are planned. These will need to be tested and evaluated before a full appraisal of this head can be made.

The Boreal head must be operated carefully; it is more subject to operator error than most of the other felling heads discussed in this report. For example, the saws and/or bearings can be damaged if the boom is pushed down onto the ground with the saws only partly retracted or if a large tree slides through the grab arms onto the saws. Other examples are that the operator must put upward lift on every tree prior to severing to avoid saw binding. If he bends the head or moves the boom during the cut, the saw or bearings may be damaged. The bearings between the saws (because of the limited space there) are not large and must not be subjected to heavy shock loads. Fragments of wood must be manually removed from between the saws from time to time to avoid saw warpage.

Butt splitting damage will be highly dependent on good operator practice. The operator must take the time to align the head on every tree to minimize butt splitting damage (similar to the Denis and Lokomo heads). In comparison the Harricana and Koehring heads are much less susceptible to poor operator practices. Also, the 10-cm kerf (includes the wood disc) of the Boreal saw wastes more wood fibre than the other heads.

The Boreal head's chain drive is not as well protected as the drive systems on some of the other heads. Also, the Boreal head (similar to the Denis and to a lesser extent, the new version of the Harricana) has relatively complex hydraulic/electrical controls and valves which may be difficult for some field mechanics to diagnose and repair. The hydraulic manifold (when it becomes available) should improve the maintainability of future units. For larger trees (e.g. B.C. Interior) the low location of the main grab arms is likely to present a problem since these trees will put great strain on the arms. The addition of "stump grabbers" to anchor the head onto the stump during felling is also necessary for these larger trees.

LOKOMO L450A CONE SAW

The Lokomo cone saw felling head was invented by a logging contractor in Finland during 1980. The patent rights were later sold to Rauma-Repola Ltd. of Finland, a forest equipment manufacturer. FERIC first saw the Lokomo cone saw demonstrated at Elmia, Sweden in June 1981. It used a new concept of felling which showed potential for reducing butt shatter caused by shears. FERIC encouraged Rauma-Repola to introduce one or more units to the Canadian logging scene for testing and evaluation. This was done in 1983.

There are currently six Lokomo cone saws in use in Finland, mostly the L450 or L450A model. One or two larger L600 models are being tested but this unit is not expected to be commercially available in Canada or Finland during the next year. The L450A has a maximum cutting capacity (including butt flare) of 45 cm (18 in). The actual maximum cutting capacity at 15 cm above the ground is 42 cm.

In operation the cutting cycle is as follows: the head is placed on a tree and the grapple arms close, pulling the head tightly to the tree. The cone, with its serrated edge, is activated by hydraulic motors. The cone revolves once. Because of the increasing taper, the cone cuts its way through the tree. For a small tree, the cone does not have to complete a revolution - the cone can be stopped as soon as a tree has been severed. The tree accumulator arm can be activated, thereby holding the first tree while permitting a second tree to be grasped and felled.

In addition to its ability to reduce butt shatter damage the Lokomo L450A cone saw has several other potential advantages:

1. It weighs only 1250 kg, including the tree accumulator arm, and tilt cylinder. Extra guarding if required, will increase the weight by about 100 kg.
2. The hydraulic system is simple.
3. The power requirement is relatively low and can be supplied by existing hydraulics on most excavator carriers (see Appendix F).
4. The cone saw turns relatively slowly; this may be less intimidating for operators and may permit better results on rocky terrain.

Rauma-Repola introduced a L450 and a L450A (A = accumulator arm) felling head to operations in Canada during 1983. The L450 cone saw mounted on a Lokomo forwarder, was tested by Takla Logging near Prince George, B.C. The other cone saw was mounted on a Drott 40 (with a Drott 50 undercarriage) owned by Case Power and Equipment of Sudbury, Ont. This unit was tested by Abitibi-Price at Smooth Rock Falls and by Spruce Falls Pulp and Power, Kapuskasing, Ont.

<u>The Lokomo Cone Saw at Takla Logging</u> was used intermittently for nearly 3 months during mid-1983, with mixed results. According to Mr. Ismo Makkonen (Rauma-Repola, Montréal) the L450 head was not suitable for the larger trees of the Prince George area. With trees over 35 cm d.b.h. the maximum moment (60,000 Nm) for the grab arm and side tilt were often exceeded. The relief valves opened, opening the arms and dropping the tree. This was particularly a problem with a large tree if its top became lodged behind another tree, or if there was a strong wind present. The cone saw cutting action however worked well.

Table 17. Stand and Terrain Factors.

	Lokomo L450A Cone Saw at Abitibi-Price, Smooth Rock Falls, Ont.
Location	30 km north of Smooth Rock Falls, Ont.
Study date	October 26, 27, 1983
Stand type	clearcutting
Species	black spruce 100%
Trees per hectare	850 (estimated)
Volume per tree	.154 m^3 (5.4 ft^3)
Terrain	lowland, classified as 4.1.1 [4]

Table 18. Production Summary

	Lokomo L450A Cone Saw at Abitibi-Price, Smooth Rock Falls, Ont.	
	time per tree, cmin	%
Move empty	2.0	5
Felling & piling	32.4	82
Move between trees	0.7	2
Move for piling	0.9	2
Delays	3.6	9
Total time per tree	39.6	100%
Duration of study, hr	7.39 PMH	
Total trees harvested	1119	
Total cycles	598	
Cycles/PMH	81	
Trees/cycle	1.87	
Trees/PMH	151	
Volume/PMH	23.2 m^3	

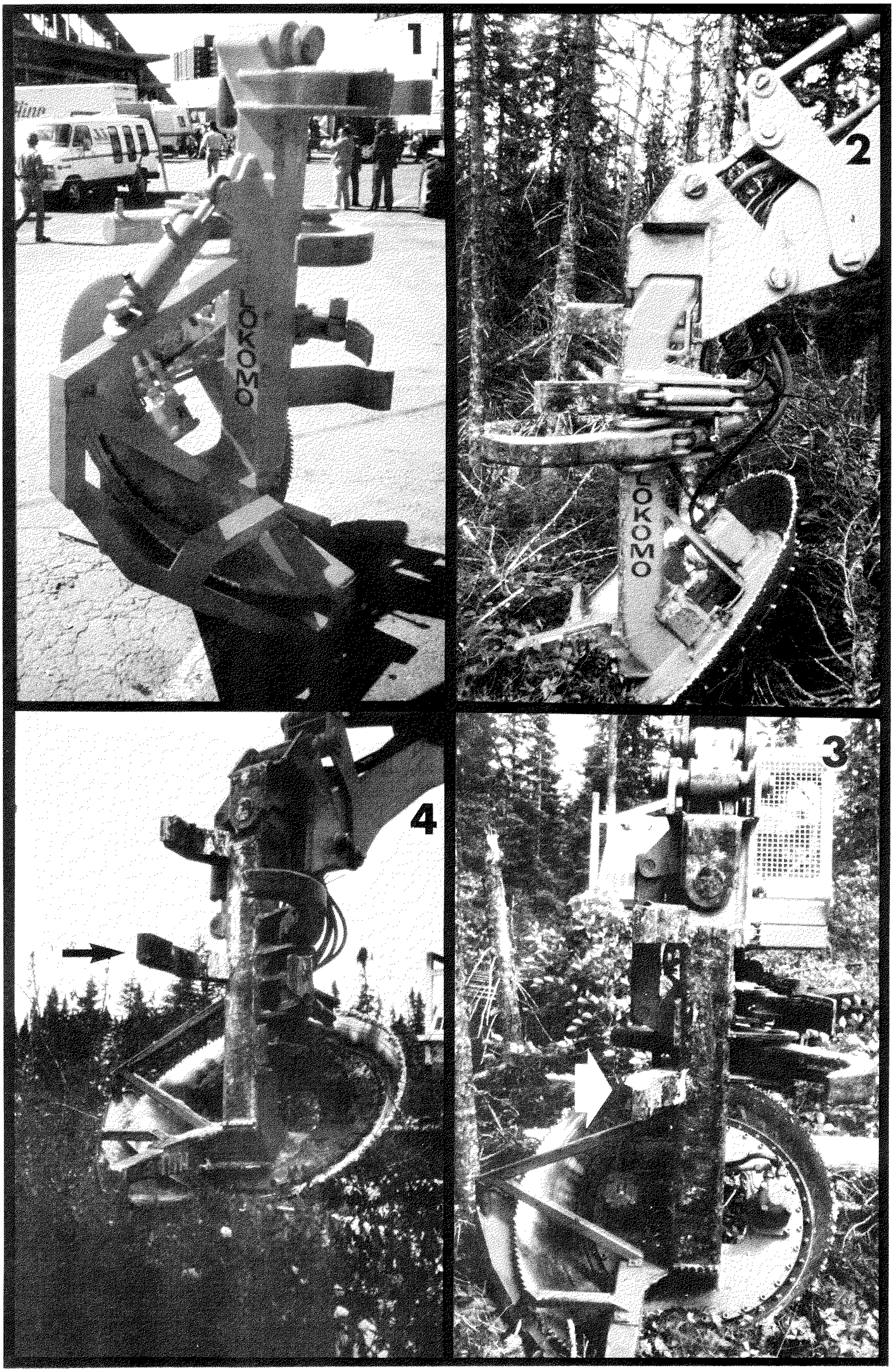


Fig. 17. Lokomo L450A cone saw; 1: unit with tilt cylinder displayed at F.I.E.E., Ottawa (Sept. 1983); 2: unit at Kapuskasing, Ont. prior to grab arm modifications; 3: unit at Smooth Rock Falls (with spacer on tilt cylinder mount) and partial grab arm changes (see arrow); 4: same as (3) but with full grab arm changes (see arrow) and tilt cylinder. This was the unit studied by FERIC (see Tables 17 and 18).

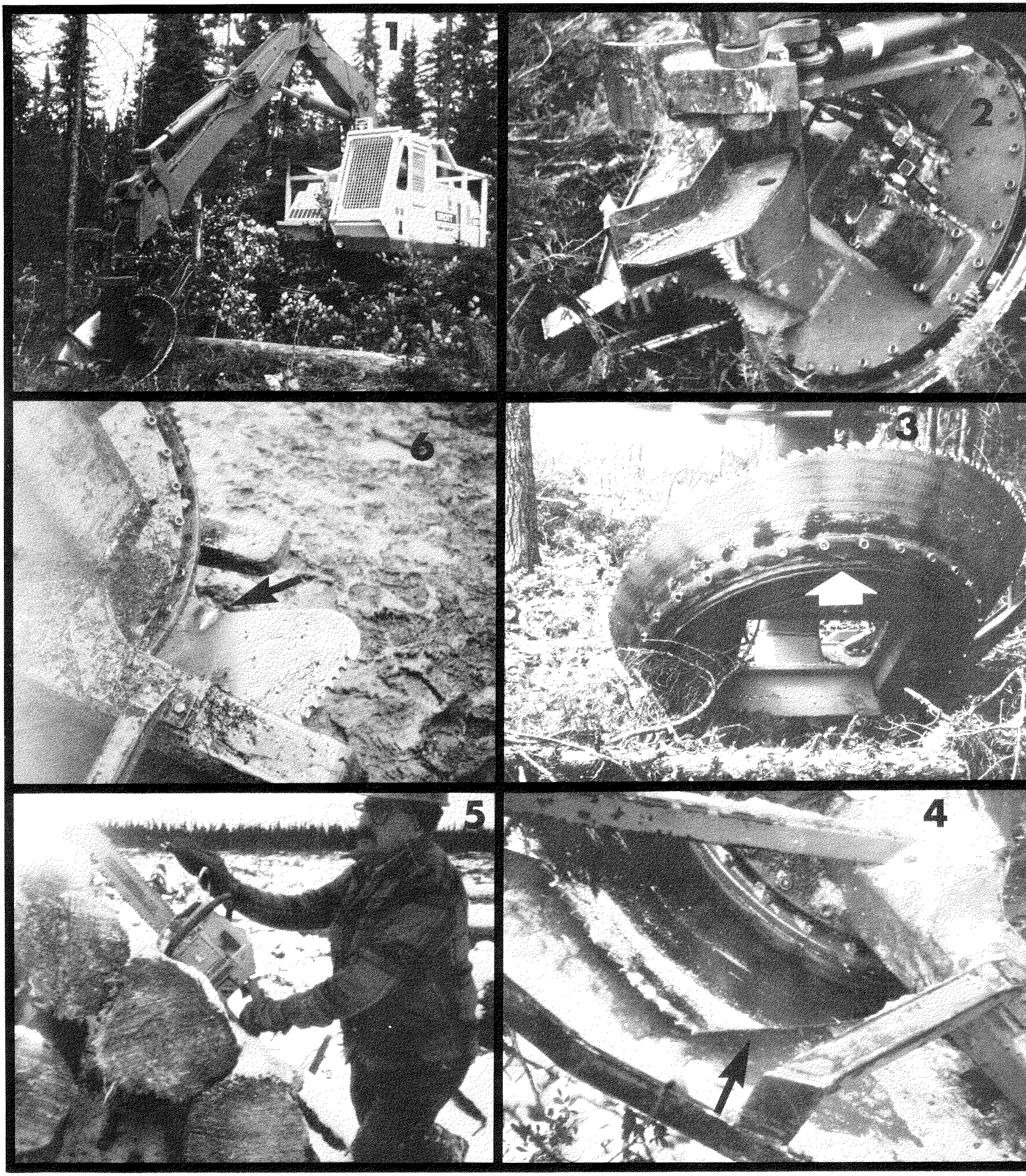


Fig. 18. Lokomo L450A cone saw; 1: on Drott 40 at Smooth Rock Falls, Ont., prior to grab arm modifications; 2: same head as (1) after grab arm modifications. Arrow indicates are of steel tubing, fittings etc. that requires better protection; 3: cone saw in "rest" position. Operator must line up mark on blade with mark on frame (see arrow) prior to cutting next tree; 4: saw blade was bent and later partially cut off (see arrow) during trial at Kapuskasing, Ont.; this reduced its cut capability from 42 cm to 35 cm; 5: the cone saw produces a rough, frayed surface. Butt splitting damage varied considerably depending on (good) operator practices; 6: welding on the cone saw head (see arrow) is difficult because of its tempered alloy steel construction.

As a result of these tests the L450 was considered to be too small a saw head for B.C. Interior conditions. Rauma-Repola plans to test a larger unit, a modified L500 cone saw in B.C. in early 1984. This unit will be designed 50% stronger than the L450 unit and will have a cutting capacity up to 50 cm, including butt flare, or 45 cm if you cut above the butt flare. A report on this test is expected to be published by FERIC's western division at a later date.

The basic price of a Lokomo L450A cone saw head in Oct. 1983 was $36,000 (f.o.b. Montréal) including the side tilt and tree accumulator features; the installation is extra. Replacement cone blades cost $2300 each. Technical specifications are provided in Appendix E.

ABITIBI-PRICE, SMOOTH ROCK FALLS, ONT.

A Lokomo L450A cone saw mounted on a leased Drott 40/50 was operated by Abitibi-Price starting in August 1983 and later again in September 1983. The Lokomo/Drott 40 was tested because the mechanical availability of the Harricana/Timbco and Denis/Timbco (see p. 22 and 36) had not proved satisfactory.

FERIC collected a few weeks of shift-level data; detailed time studies were also made. During its first two months at Abitibi-Price the Lokomo/Drott had difficulty in accumulating trees; usually it felled and bunched only one tree at a time (see Fig. 17). During October 19 to 22, 1983 the cone head was modified to permit better holding of two or even three trees: the accumulator arm was lowered to below the main grab arm and a bigger cylinder was installed on it; two additional solid arms were added on the LHS (viewed from the operators cab); also the length of the main grab arm was extended on the RHS. These changes resulted in a very significant increase in productivity since they permitted better tree accumulation (see Fig. 17). Also, grease fittings were added to the cylinders.

The Lokomo/Drott 40 was operated in black spruce stands similar to the Denis/Timbco (see p. 36). It was operated on a 2-shift-per-day basis, 5 days per week. The operators were paid on an hourly basis with no bonus provision.

Production: Prior to the grab arm modifications the operator was usually unable to fell more than one tree per felling cycle. The *detailed time study* results presented in Table 17 and 18 were made after the grab arm modifications. The average productivity during the detailed time study was 151 trees/PMH or 23.2 m^3/PMH, based on an average tree size of .154 m^3. These results indicate that the grab arm and accumulating arm were working well. However, its ability to accumulate is less than for the other felling heads studied in this report. It was limited to two 20-cm trees per cycle.

> *Prior to the grab arm modifications* (see Fig. 17) the operator was limited to one (or sometimes two trees) per felling cycle. This limitation restricted productivity. When the operator would try to accumulate a tree, it often slipped sideways (jack strawed) out of the lower part of the head. To correct the jack strawing problem and to permit improved tree accumulation it was decided to modify the grab arms, as described in the previous section (see also Fig. 17).
>
> *After the grab arm modifications* the unit worked well. No jack strawing problems occurred during FERIC's detailed time study.

Repairs: Based on nearly three months operating experience obtained to date, Abitibi-Price has experienced no major mechanical problems with the exception of one cone saw blade failure caused by the operator (see below). There has been no overheating of the Drott 40's hydraulic oil or engine. There have been (as expected) repairs to hoses and hydraulic fittings on the head. FERIC has expressed concern about insufficient guarding for the hydraulic components on the head, particularly the rigid tubing connected to the saw motors and the hoses and fittings at the back of the head. All of these components are susceptable to damage from above, if for example a section of a broken tree falls onto the back of the head.

Sharpening of the cone saw is seldom necessary. At Abitibi-Price the cone saw was sharpened only once. According to Mr. Ismo Makkonen of Rauma-Repola Int. this is similar to the experience in Finland. Blade life is a different concern; the limited operating experience at Abitibi-Price provides little insight on this aspect. For example, to date there has been no winter experience with the Lokomo saw blades in Canada. The cold temperatures of the Canadian winter combined with the high torque forces on the turning saw blade may present a potential problem. The reported experience in Finland is that cone blades usually last for about 80,000 trees, provided that they have no contact with rocks. Although neither the Takla Logging or Abitibi-Price unit have worked in rocky terrain conditions, cone blade replacement costs in rocky terrain may be high. Because of the high torque forces on the saw the teeth can be expected to bend (or cut the rock) during the cutting action. The Lokomo cone saw blade is made from specially tempered alloy steel. Welding on this type of steel may not be successful because it can change the molecular structure of the steel. Also (for the same reason) it is unlikely that the cone saw teeth can be resurfaced using a welding technique. (NOTE - In contrast, resurfacing of teeth (using a welding technique can usually be done on Harricana saw blades.) To overcome potential problems with cone saw blade damage from rocks it may be possible to install guarding for the saw, similar to that shown on Fig. 17, on both sides of the head. This, plus turning the cone blade only to the point where the tree is severed, and then lifting and turning the blade back to its rest position, should limit potential cone blade damage in rocks. The small basal area of the Lokomo head permits the head to be placed between rocks better than circular saw heads.

An actual cause of cone blade failure (which occurred once at both Takla Logging and Abitibi-Price) resulted from the operator's failure to bring the cone saw fully back to its "start" position prior to cutting the next tree. When cutting the next tree, the high torque on the improperly positioned blade caused the blade to bend. Although the blade was straightened, Abitibi-Price noted that it soon developed a stress crack at the bend and required replacement. NOTE: An automatic return device for the saw blade to return to "start" position should be considered by Rauma-Repola.

FERIC briefly observed the Lokomo cone saw in operation at Spruce Falls Pulp and Paper, Kapuskasing, Ont. during a two-week test there in August, 1983. Two problems with the cone saw blade (which costs $2300) were noted: Several locking nuts came off the narrow tapered end of the cone blade. Also, the wide end of the cone blade was bent when it was inadvertently struck against a tree; it was cut off and the blade was later replaced (see Fig. 18).

Limited operating experience to date with the Lokomo cone saw head does not permit a comprehensive assessment of its mechanical reliability. Indications to date however are good, not withstanding FERIC's (earlier stated) concern about insufficient guarding for hydraulic components and the concern about blade life, particularly in rocky terrain. Additional concerns, stated below are based on operating experience with other saw heads, not on actual results with the Lokomo unit.

The Lokomo cone saw blade, when in its retracted position, is not as well protected as the saws on the Denis, Harricana and Boreal heads. For example, if the carrier became stuck, could the Lokomo head be used to push the machine out of its predicament? Also, it is a common practice for some feller buncher operators to scoop a hole with the felling head, prior to downpiling trees, to permit easier placement of chokers for skidding bunches. Is this possible with the cone saw? Also, the greater weight and better protection for hydraulic components can be an advantage when pushing down chicos or unmerchantable trees. Additional operating experience is required to access these factors.

Butt Damage: FERIC observations of summer butt damage at Abitibi-Price (and earlier at Spruce Falls Pulp and Power) indicate that the Lokomo cone saw can reduce butt splitting damage as compared to shears. This is a result of the "sawing" action used by the cone saw and the fact that the tree does not need to be bent forward during the severing action to "open the kerf". NOTE - "opening the kerf" on chain saw felling heads is often a cause of butt splitting damage (e.g. Kockums chain saw head - Appendix A).

The Lokomo cone saw can also cause butt splitting because the tree must be firmly grabbed prior to severing. The grabbing action can place bending stresses on the tree during the cutting action which can result in splits. In this respect the Lokomo cone saw is similar to the Denis and Boreal felling heads, which must also firmly grab the tree prior to severing. For the Lokomo head, the second (or third) tree cut during a felling cycle is more likely to have more butt damage than the first.

The Lokomo cone saw has, to date, only operated in eastern Canada on soft, flat ground. FERIC studies have showed limited butt splitting damage under these conditions after the operator becomes experienced. However, in winter conditions (when butt splitting damage from shears is also worst) when the wood fibres are non-elastic and tree stumps are frozen rigid (or when working on uneven ground) more splitting damage may result. Winter tests, of butt damage are required.

The degree of butt splitting damage will likely be highly dependant on the operator. A careless operator who does not align the head carefully on each tree will cause more butt damage than a careful operator. As stated earlier (p. 44), a compromise must usually be made between maximizing productivity and minimizing butt splitting damage.

The Lokomo cone saw produces a rough, frayed cutting surface (see Fig. 18) similar to the Koehring disc saw. This may create problems for butt scaling since it may be difficult to determine the extent of butt rot.

The small basal area of the Lokomo cone saw permits it to cut nearly at ground level. Although this is useful for preventing high stumps, particularly on trees growing close together, it can result in butt flare on the felled trees. Operator attention to this factor and/or a tubular spacer welded to the bottom of the head should eliminate this potential problem. A better solution to maximize wood fibre recovery, would be to install a butt end reducer at the mill (see p. 53).

GENERAL COMMENTS

The operating experience at Abitibi-Price (Smooth Rock Falls), based on three months of machine use in relatively small tree sizes, has been favourable. Both the Drott 40/50 carrier and the Lokomo cone saw have performed well with relatively few repairs required to either. The productivity (on a PMH basis) after the grab arm modifications were made, improved substantially; it is now similar to the Denis and Boreal circular saw felling heads. NOTE: The performance of a L450 cone saw head operating in much larger trees near Prince George, B.C. has provided mixed results to date. The L450 was considered to be too small for B.C. Interior conditions. Rauma-Repola plan to test a modified L500 version in early 1984 in the B.C. Interior.

The Lokomo L450A is a light-weight felling head (1250 kg) that can be installed on many different types of carriers. In this respect it has an advantage over the circular saw felling heads, including the Denis and Boreal units. A lighter, smaller carrier may permit lower capital and operating costs. The hydraulic flow required by the cone saw can be supplied by existing hydraulics on most carriers; again this is advantage over several of the circular saw heads. The light weight of the head will reduce the stress on the boom, boom pins and turntable components, as compared to heavier felling heads. If brushing of large non-merchantable trees must be done frequently the Lokomo head will likely be considered too light and unprotected. Also, the location of the connecting pin at the top of the head may not be suitable for "large tree" applications; more operating experience is required.

The limited operating experience with the Lokomo cone saw to date does not permit a comprehensive assessment of the unit's mechanical reliability; it is also the main reason why this head has been classified as a "pre-production" unit by FERIC. FERIC's main concern is with the life of the cone saw blade (since it cannot be effectively welded) and with protection for the rigid tubing, fittings and other hydraulic components on the head. For rocky terrain, additional protection for the cone saw also seems necessary. Other possible limitations, such as the ability of the head to push the machine out of a hole when stuck, have also not been assessed.

FERIC observations of summer butt splitting damage indicate that the Lokomo cone saw can significantly reduce butt splitting damage, as compared to shears. However, since the tree must be firmly grabbed prior to severing it is likely that some degree of butt splitting will occur, particularly in winter conditions when the wood is non-elastic and the stumps are rigid, and on uneven terrain. A careless or inexperienced operator will cause much more butt damage than a careful operator. In this respect the Koehring and Harricana heads have an advantage. Because they sever the tree before grabbing the butt, they are much less susceptible to poor operator practice.

CONCLUSIONS

The main conclusions of this report are summarized in Table 19, where the 5 heads are compared and contrasted on the basis of various criteria. In FERIC's opinion three of the felling heads can be classified as "production models" on the basis that these units have been used in regular production for extended periods of time. The Koehring, Harricana and Denis heads fall into this category. In contrast, the Boreal and Lokomo heads should be regarded as "pre-production models". These two heads have not been extensively tested (in a variety of operating conditions) in Canada; also significant changes are planned both to the Boreal unit and to the Lokomo head (B.C. version). Further operational testing will be required to prove their reliability and productivity.

Table 19 compares and contrasts only the latest version(s) of each respective felling head. The specifications for the latest version(s) are provided in Appendices B to F. The reader is cautioned in this respect because the contents of Table 19 may (in some cases) disagree with the results of data collection from earlier versions of these heads. In such cases the earlier head(s) have been regarded as prototypes. This applies particularly to the Koehring disc saw at Dubreuilville, and to the Harricana head - at all three locations, Hearst, Iroquois Falls, Ont. and Amos, Qué.; the latest versions of these are much improved.

Other criteria for purchase that are not compared in Table 19 are parts stocking levels and "in-field" repair service that is available from the local dealer. The prospective buyer of a "non-shear" felling head is advised to compare the level of parts stocking by his dealer, at the local or regional level, with that for other heads (perhaps at other dealers). He should also compare the quality and speed of "in-field" service that he is likely to receive for both warrantee and non-warrantee work. These factors are important since unexpected diagnostic and repair downtime can be costly.

Table 19. Summary and Main Conclusions.

	KOEHRING DISC SAW	HARRICANA CIRC. SAW	DENIS SJ-24 TWIN SAW	BOREAL DD-20 SAW	LOKOMO L450A CONE SAW
Maximum Cut at Stump	50 cm (20 in)	50 cm (20 in)	50 cm (20 in)	45 cm (18 in)	42 cm (17 in)
Cutting Technique	scything or frontal	frontal	frontal	frontal	frontal
Head Weight - includes head, saw(s), boom adaptor, two sets of grab arms and side-tilt attachment.	2360 kg (5200 lb)	- standard version: 2230 kg (4900 lb). - heavy duty version: 2600 kg (5700 lb).	1800 kg (4000 lb)	1100-1700 kg (2420-3740 lb) - depends on version	1250 kg (2750 lb)
Carrier Required - excavator type	Koehring recommends a carrier with a minimum weight of 22,700 kg (50,000 lb) having 100 kW (135 hp) net engine power. The Koehring 266-FB, Cat 225,227 and Hitachi UH122 have been used successfully.	smaller carriers (as compared to the Koehring disc head) can be used: In eastern Canada, the Drott 40 and JD693 have been used successfully. In the B.C. Interior (larger trees - and heavy duty version head) the Drott 50, Cat 225,227 are more suitable.	smaller carriers (as compared to the Harricana circ. saw) can be used because of Denis' lighter weight and lower hydraulic requirement. In eastern Canada, the Timbco 2518 can be used; in the B.C. Interior the Drott 40 and JD693 are often used.	- similar to the Denis head.	- similar to the Denis head.
Hydraulic Requirement	- an independent saw circuit is used on all Koehring carriers (266-FB, KFF, K2FF) which provides 1.8 L/sec (29 GPM) @ 31,000 kPa (4500 p.s.i.). With the "scything" method of felling, flow is required for the saw, swing, main and stick boom at the same time. The grab arms require 1.3 L/sec (20 GPM) @ 17,000 kPa (2500 p.s.i.). - provisions should be made for extra oil cooling capacity as compared to using shears. The disc blade rotates continuously. Heat is generated in the hydraulic system if the saw stalled or slowed down frequently.	- it is preferable to have the saw on a separate circuit. The saw requires a minimum flow of 2.5 L/sec (40 GPM) @ 17,000 kPa (2500 p.s.i.). If the saw is not on a separate circuit, the grab arms (which must operate quickly) may be sluggish. Larger pumps (providing up to 6.3 L/sec (100 GPM are desirable to provide additional power to the saw when accelerating. - on most carriers, extra cooling capacity is required (as compared to using shears). The saw rotates continuously. Heat is generated in the hydraulic system if the saw is stalled or slowed down frequently.	- requires a minimum flow of 2.8 L/sec (45 GPM) @ 17,000 kPa (2500 p.s.i.) for the saw and (simultaneously) 1.3 L/sec (20 GPM) for the saw feed. It does not require a separate circuit for the saws. Total carrier hydraulic flow requirement is 4.4 L/min (70 GPM) @ 17,000 kPa. - existing pumps and cooling systems are usually adequate provided the saws are not stalled frequently. The Denis saws are turned off/on for cutting each tree.	- similar to the Denis. - existing pumps and cooling capacity are usually adequate.	- requires a flow of 4.2 L/sec (66 GPM) @ 17,000 kPa (2500 p.s.i.) - existing pumps and cooling capacity are usually adequate.
Saw Blade(s) Information	for "standard" blade: - blade diameter 140 cm; thickness 2.54 cm; replaceable carbide tips on 18 (welded-on) replaceable teeth. - blade speed 1200 RPM, depends on carrier. - rotation: left or right HS. - blade replacement cost $2400.	for "standard" blade: - blade diameter 137 cm; thickness 1.27 cm; single piece bent tooth design with 36 teeth; made of alloy steel. - blade speed 1100-1300 RPM; depends on carrier. - teeth that are damaged (from repeatedly striking rocks) are built up using a welding technique (hard facing) and are then ground into shape. - blade replacement cost $1400.	- several different designs of 61-cm diameter saws are used. In the Prince George, B.C. area, flame-cut blades of CHT 360 steel, 1.27-cm thick, with replaceable carbide tips are used.	- two 71-cm diameter Simons saws with replaceable teeth and bits are used. - blade speed is 2000 RPM. - sealed roller bearings are used between the two saws. - saw replacement costs per set of 2 is $800.	- the cone blade is .8 cm thick and is made of high strength tempered alloy steel. It is rotated by three hydraulic motors located on a large ring gear. - cone saw replacement cost is $2300.
Production - based on FERIC data collection and interpretation.	- highest producer of the 5 heads when installed on a suitable carrier. This applies to the "scything" technique when used for large or small trees.	- second highest producer of the 5 heads studied. Usually less time is required to align the head and sever the tree - to achieve minimal butt damage - as compared to the Denis, Boreal and Lokomo heads. NOTE: The productivity is similar to a similar capacity shear on the same carrier.	- production is usually 10% lower than the Harricana circ. saw (on a PMH basis).	- production is similar to the Denis head.	- production is similar to the Denis head.
Operational Aspects	- the "scything" technique with the Koehring head requires operator skill and attention. He must operate several functions (swing, main boom, stick boom) simultaneously. Depth perception is important. Also, the operator must grab the tree immediately after severing.	- the 5-button joystick for the Harricana head may require more time to learn for a new operator than the Denis, Boreal or Lokomo heads. - dropped trees are somewhat difficult to pick up. - deep snow is usually no problem since the saw acts as a snow blower.	- a new operator can learn to operate it fairly quickly. - the 30-cm wide arms that carry the saws may be difficult to insert between trees growing close together.	- a new operator can learn to operate it fairly quickly. - its narrow width and light weight make it easier to place on a tree. - the main grab arms are located too low on the head for large trees.	- a new operator can learn to operate it fairly quickly. - lacks adequate guarding for "brushing" large, dead or unmerchantable trees. - tree accumulation is more limited than on other heads. e.g. 2 trees @ 15-cm per felling cycle is maximum.
Mechanical Aspects	- rugged head (e.g. for "brushing"). - simple hydraulics (i.e. no electrics or valves mounted on the head). - has a butt plate to support accumulated trees, prevent saw bending and to protect the saws from shock loads. - very few parts. - head maintenance is simple - most can be done by the operator. - saw blade maintenance is a problem only for rocky terrain conditions.	- rugged saw head (e.g. for "brushing"). - moderately complex hydraulics (e.g. there are 3 Monson-Tyson solenoid valves on the head; grab arms (2), saw feed. This makes it more complex (for diagnosis & repairs) than the Koehring disc head but less than the Denis and Boreal heads. - saw blade maintenance is minimal in rock-free terrain (e.g. on some operations the teeth are sharpened once in two months. - saw life is excellent in summer; more winter experience is required. - has a butt plate (similar to the Koehring). - the Harricana head, since it is heavier than the Denis, Boreal and Lokomo units may cause more wear on boom pins etc. on marginal carriers.	- the main problem with the Denis head is the complexity of its hydraulics and electrics. This can create considerable diagnostic problems, especially for field mechanics not familiar with these components. To carry out repairs everything has to be checked in the proper order - it may take several hours to find the cause of a problem. All head functions, including the saws, are conrolled by pilot-operated solenoid valves on the head. There are also many check valves (which can cause problems) and several "accessory" valves (e.g. rated feed flow valve, automatic lock on arms during felling, automatic saw retract device) which have proved troublesome on other machines. NOTE: a hydraulic manifold would help to reduce diagnostic problems. - saw motor bearings have caused problems on some units in the past.	- the Boreal head (similar to the Denis) has complex hydraulics/electrics. All head functions are controlled by solenoid valves on the head. It also uses several "accessory" valves. The hydraulic manifold that is planned for future units should improve this aspect. - the saw bearings are limited in size because of limited space between the saws. - chain drive is exposed and can be damaged. - no butt plate to support accumulated trees.	- the Lokomo has a simple (direct) hydraulic system - easy to diagnose and repair. Additional guarding is needed to protect the hydraulic fittings, motors, etc. on the head. For rocky ground protection for the LHS of the cone saw should be considered. - for B.C. Interior conditions several major modifications are required (see p.59).

	KOEHRING DISC SAW	HARRICANA CIRC. SAW	DENIS SJ-24 TWIN SAW	BOREAL DD-20 SAW	LOKOMO L450A CONE SAW
Rocky Terrain	- not recommended for rocky ground because the "scything" action (particularly in snow) is likely to hit rocks. When the "seat" of the carbide tips on the saw teeth are damaged (badly) the disc blade must be removed and repaired and a spare installed. "Bolt-on" teeth may overcome this problem in the future, if they prove successful.	- reasonably successful in rocky terrain. This depends however on a careful operator, especially if working in deep snow. - a reliable portable grinder (and electrical hook-up) on the carrier should help in this respect - to regrind damaged teeth without removing saw blade.	- reasonably successful on rocky terrain with flame-cut saw blades. This depends however on a careful operator, especially when working in deep snow. - carbide-tipped teeth are not useful for rocky ground. - Simons saws with replaceable teeth do not work well in rocky ground.	- unknown at present. No experience to date in rocky terrain.	- unknown at present. No experience to date. - the small basal area of the Lokomo head should permit its placement between rocks. However, once the saw is broken or damaged the cone blade cannot be effectively welded or repaired - because of the high strength alloy steel used and the high torque forces on the blade. Blade replacement costs in rocky terrain may therefore be high.
Butt Splitting Damage - assumes that all heads have two sets of grab arms and a side-tilt feature.	- almost none - because the tree is grabbed after it is severed. As a result butt splitting is not affected by poor operator practise. An exception to the above, illustrated in Fig. 15.	- similar to Koehring disc head.	- butt splitting damage varies considerably between operators - it depends on good operator techniques. The operator must align the head carefully on each tree to avoid placing bending stresses on the tree during the severing action. - on the latest version (Nov. 1983) several improvements help reduce butt splitting damage (i.e. feed speed regulator valve, support wedge behind the saws, side tilt on head).	- similar to the Denis and Lokomo heads the operator must align the head carefully on each tree to avoid placing bending stresses on it during felling. This is more difficult to do on uneven (sloping) terrain than on flat ground. Also, the second (or third tree) cut during a felling cycle has more chance of split damage than the first.	- butt splitting damage can easily occur with the Lokomo head, especially on the second tree cut during a felling cycle. Also, the operator must align the tree properly in the saw pocket and at the grab arms or the high saw torque forces will cause splitting on the last part of the cut. Similar to the Denis and Boreal heads, butt splitting damage depends on good operator techniques.
Butt Surface Roughness - varies with sharpness of teeth, season of year, species, etc.	- rough, frayed surface - this can make butt rot determination difficult.	- medium roughness - it may make butt rot determination difficult.	- smooth surface with Simons saws - slightly rougher with flame cut saws.	- smooth surface.	- very rough, frayed surface - this will make butt rott determination difficult.
Saw Kerf (wood removed).	5 cm	4 cm	2 cm	10 cm	2 cm
Stump Height	- depends on operator - usually it is similar to shears. - in deep snow the saw acts as a snow blower - high stumps are not a problem.	- depends on operator - usually it is similar to shears. - high stumps can occur if several trees are close together (e.g. clumps). - in deep snow the large base of the Harricana head presents few problems with stump height. The saw acts as a snow blower.	- depends on the operator - usually it is similar to shears. - a "staircase effect" can result if several trees are cut behind each other. - the 30-cm wide arms that carry the saws may be difficult to insert between trees growing close together.	- depends on the operator. - the narrow width of this head and the narrow fixed arms at the base make it possible to insert between trees growing close together.	- depends on the operator. The head can cut right at ground level if desired.
List Price (Nov. 1983) - complete with saw(s), boom adaptor, two sets of grab arms and side-tilt attachment.	$52,200 - f.o.b. Brantford, Ont. - not including installation.	- standard version - $46,500. - heavy duty version - $48,800. - f.o.b. Amos, Qué. - installed price.	$44,500 - f.o.b. Ste. Rosalie, Qué. - plus $1000-$2000 for installation.	$39,000 - f.o.b. Macamic, Qué. - installed price.	$36,000 - f.o.b. Montréal, Qué. - not including installation.
Units Sold/Leased To Date (Nov. 1983). - in Canada & U.S.A.	4 east 12 west	15 east 20 west	10 east 20 west	1 east 1 west	1 east 1 west (plus 6 in Finland)
Summary	- the Koehring disc head, after several years of development, can be considered fully developed. Its mechanical reliability is now very good. When using the "scything" technique it has the highest productivity of the 5 heads studied. Butt splitting is virtually non-existant and is not "operator-dependent". - the disc head usually requires a larger carrier than the other heads which may mean higher capital costs and higher fuel consumption. A separate hydraulic circuit (pump) for the saw is required. - the operator technique when "scything" is more difficult to learn - but this is not a major problem. - the main practical limitation to the use of the Koehring disc head is that the saw blade must be removed to repair (badly) damaged teeth. This procedure causes too much downtime and prevents the effective use of the Koehring disc head in rocky terrain. This problem is currently being addressed by Koehring. It is possible that "quick-disconnect" removable teeth may help resolve this problem in the future.	- the Harricana saw head, after several years of development can be considered fully developed and mechanically reliable. It had the second highest productivity of the 5 heads studied. Butt splitting is virtually non-existant and is not "operator-dependent". - the Harricana head is heavier and requires a larger hydraulic flow than the Denis, Boreal or Lokomo heads. Extra hydraulic cooling capacity is also necessary since the saw turns continuously. The saw and grab arms should be on separate hydraulic circuits (pumps). The higher weight and flow requirements of the Harricana head may limit the number of suitable carriers on which it can be mounted, especially for soft ground conditions. - the Harricana head has been used successfully in rocky terrain although the operator must be careful. The Harricana with its 5-button joystick is more difficult to learn to operate than the Denis, Boreal or Lokomo heads but this is not a major concern. The 3 Monson Tyson valves on the head appear to be more reliable than those used on other heads. Saw teeth sharpening in rock-free conditions is seldom necessary. In some cases it is done only once in 2 months. - Damaged saw teeth are built up using a welding technique and are then ground into shape with a hand grinder - this can be done without removing the saw, if required. Saw life has proved excellent in both summer and winter conditions although there is limited information available for winter.	- the Denis twin saw head has a basic productivity slightly (10%) less than that for the Harricana saw head. Earlier problems with butt splitting have been reduced on the latest version; however butt damage is still dependent on good operator techniques. Careless operators can cause butt splitting by placing stresses on the tree during the severing action. - the lower hydraulic flow requirement and lighter weight of the Denis head may be an advantage (vs. the Harricana) for some carriers. - the hydraulic (electrical complexity of the Denis may cause problems for diagnosis and repairs, especially for field mechanics unfamiliar with these type of components. The saw, 2 sets of grab arms tilt and saw feed are all controlled by solenoid valves on the head. In addition there are several "accessory" valves and numerous check valves. Saw motor bearings have caused problems on some units.	- the Boreal head is a newcomer that is still in the pre-production stage. Its productivity is similar to the Denis and Lokomo heads. Large trees (40-50 cm at the stump) occasionally cause problems because of the force required to split the wood disc between the saws. The amount of butt splitting that occurs is dependent on proper operator technique. Like the Denis and Lokomo units it has no butt plate to prevent saw binding and to protect the saws. - although the head is light and narrow and has lower hydraulic flow requirements (as compared to the Harricana) it also has several disadvantages: the saw kerf (10 cm) wastes wood fibre; the head has a relatively complex hydraulic system (i.e. saw, grab arm tilt and saw feed are all controlled by solenoid valves) - also it has several "accessory" valves - which have proved troublesome on other machines. - the present design needs modifications to be suitable for the larger trees of the B.C. Interior. The main grab arms are located too low on the head - for large trees. The mechanical reliability of the (exposed) chain drive may be a problem if foreign objects (e.g. stones) enter this part of the head. Lubrication of the chain drive may also prove to be a problem.	- the Lokomo head is a newcomer that is still in the pre-production stage vis-à-vis its use in Canada. Its productivity is similar to the Denis and Boreal heads. The amount of butt splitting that occurs depends on proper operator techniques. Splitting damage occurs more easily on the second tree cut. Its accumulating ability is usually limited to two trees @ 15 cm; its maximum cut at the stump is 42 cm; this is less than for the other heads. - the Lokomo head is light, narrow, has relatively low hydraulic flow requirements and has a simple (easy to repair) hydraulic system with no electrical features on the head (the hydraulics on the head require better guarding however). - its main limitations at this point appear to be butt damage and the lack of knowledge about blade life, particularly in regard to the following factors: rocks, frozen wood and large trees. Unlike some of the other saw blades it cannot be (properly) repaired by welding because of the high strength alloy steel used and the high torque forces on it during severing. Hard facing on dull teeth may be possible however. - the unit at Abitibi-Price (Ont.) has performed well to date in small trees. The B.C. unit requires considerable modifications.

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APPENDIX A

BUTT DAMAGE LEVELS OF NON-SHEAR FELLING HEADS

This Appendix is based on Special Report No. SR-19A "Butt-Damage Levels of Non-Shear Felling Heads in British Columbia", June 1983 by D.Y. Guimier of FERIC's western division [8]. It provides butt damage information collected in the B.C. Interior during the winter of 1982-1983.

The report concludes: "All types of non-shear felling machines significantly decrease butt damage and lumber loss as compared to (single blade) shears. A reduction in the percent lumber loss by a factor of 4 to 10 can usually be expected. The percent lumber loss for non-shear machines winter tested, ranges from .12% to 1.86% (see Table A.2), with 85% of these machines producing less than 1% loss. The two shears averaged 4% loss".

Table A.1. Description and Location of the Felling Systems Studies for Butt Damage.

MACHINE	MAX. STUMP DIAMETER cm (in)	CARRIER	LOCATION	ABBREVIATED NAME
Anda Feller Buncher	61 (24)	Drott 50	Ft. St. James	Anda
Drott Auger Feller Buncher	61 (24)	Drott 50	Prince George	Auger
Dag Chainsaw Director	51 (20)	Komatsu D65	Ft. St. James	Dag
Denis Feller Buncher	51 (20)	Drott 40	Fraser Lake	Denis
Dika Feller Buncher	71 (28)	Cat 235	Prince George	Dika
Hand Faller	N/A	N/A	Prince George	Hand Faller
Harricana Feller Buncher	56 (22)	Cat 225-235	Ft. St. James	Harricana 1
Harricana Feller Buncher	51 (20)	Drott 40	Kamloops	Harricana 2
Hultdins Felling Saw	61 (24)	TJ520 Clambunk	Telkwa	Hultdins
Kockums Feller Buncher	55 (22)	Drott 40	Princeton	Kockums 1
Kockums Feller Buncher	55 (22)	J.D. 693-B	Princeton	Kockums 2
Northwood/FERIC Feller Director	91 (36)	FMC	Prince George	NW/FERIC FD
Osa 670 Feller Buncher	56 (22)	Osa	Houston	Osa
Spencer Feller Buncher	48 (19)	Drott 40	Princeton	Spencer
QM Shear (Snipper)	71 (28)	Cat D7G	Prince George	QM Shear 1
QM Shear (Snipper)	71 (28)	Interna-tional 175	Prince George	QM Shear 2

Table A.2. Butt-Damage Summary

RANK	FELLING SYSTEM	PERCENT LUMBER LOSS (2X6 BASIS)	PERCENT OF TREES WITH DAMAGE	AVERAGE BUTT DIAMETER (cm)
1	Hand Faller	0.05	4	35.3
2	Spencer	0.12	16	36.1
3	Harricana 2	0.17	13	28.0
4	Harricana 1	0.20	16	31.5
5	Dag	0.41	34	30.4
6	Dika	0.45	41	34.6
7	Osa	0.49	29	27.1
8	Kockums 2	0.63	66	31.7
9	Hultdins	0.67	57	37.1
10	Auger	0.73	29	25.5
11	Anda	0.88	59	34.5
12	Kockums 1	0.92	42	31.0
13	Denis	1.28	40	25.8
14	NW/FERIC FD	1.86	77	40.7
15	QM Shear 1	3.36	100	41.1
16	QM Shear 2	4.54	98	30.3

Detailed results by diameter classes, species and different lumber classes are available on request from FERIC.

The above study does not include information on the Koehring disc saw, the Lokomo cone saw or the Boreal double deck saw because there were no units operating in B.C. during Jan.-Feb. 1983, when the study was conducted.

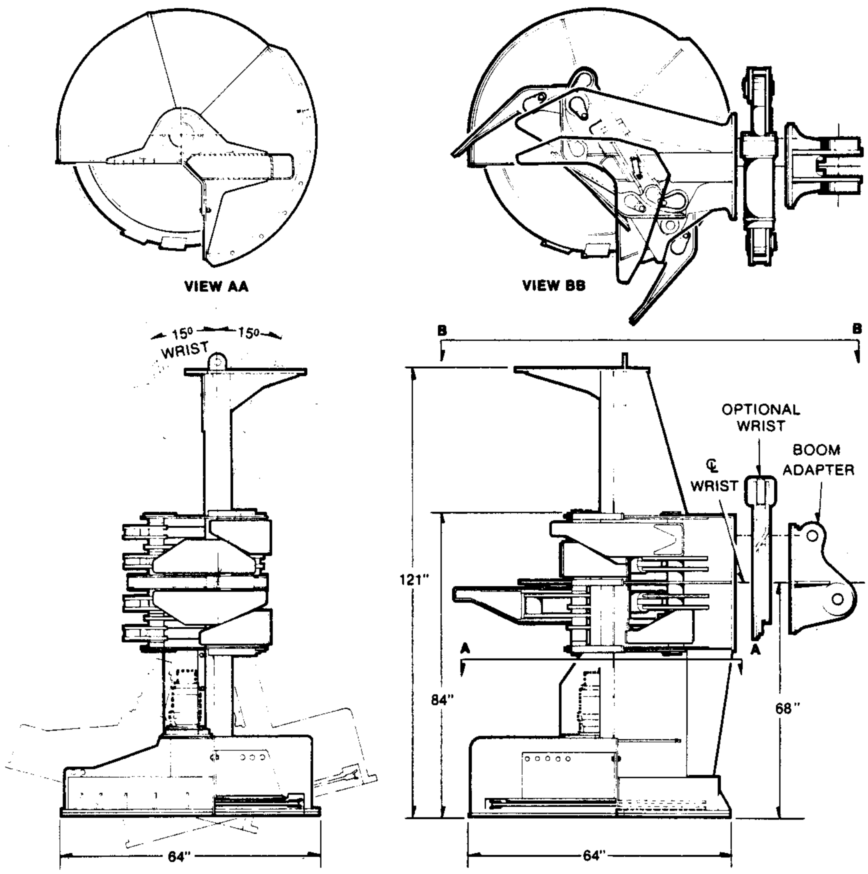
During the summer and fall of 1983, FERIC's eastern division carried out additional butt damage studies of Koehring, Boreal and Lokomo units using the same procedure used by D.Y. Guimier in B.C. The results are summarized below:

Felling system	Percent lumber loss (2 x 6 basis)	Percent of trees with damage	Average butt diameter (cm)
Koehring Disc Saw	.36	4	25.6
Boreal	.79	15	25.3
Lokomo 1 (experienced operator)	.58	19	23.0
Lokomo 2 (inexperienced operator)	.68	32	27.0

These results confirm FERIC's earlier findings that butt damage with the Koehring disc saw is minimal [1]. Butt damage is minimal because (similar to the Harricana circ. saw) the tree is grabbed after it is fully severed. Butt damage can occur with the Koehring disc saw if a tree is leaning toward the machine and is pushed by the top of the saw head during the severing action (see Fig. 11).

APPENDIX B

KOEHRING DISC SAW SPECIFICATIONS



LEFT HAND SHOWN. RIGHT HAND OPPOSITE — FOR R.H. MOUNTED CABS.

KOEHRING CANADA

KOEHRING
20" disc saw felling head

Upper Tree Guide:
Increase clamp arm leverage on stem for improved large tree handling.

Optional Wrist (side tilt) Attachment:
Bolts between felling head and boom adapter as illustrated. Compact overall width of 3.5".

Cylinders:

	Optional Wrist	Clamp Arms (1 per Arm Set)
Bore Dia.	5.0	4.0
Rod Dia.	2.25	2.0
Stroke	11.5	8.5
Maximum Operating Pressure	3000 PSI	3000 PSI

Weights:
- Head assembly complete with 1" disc blade and two sets multi-tree clamp arms as shown .... 4400 lbs.
- Boom adapter .... 280 lbs.
- Optional wrist (side tilt) attachment .... 560 lbs.

Tree Size Capacity: .... 20" diameter nominal

Disc Saw Blade:
Replaceable carbide tips on replaceable high strength steel teeth.
55" overall diameter; 2" kerf (cut) width with standard 1" thick disc.
Blade Speed: 1100 rpm average depending on base machine model.
Rotation (away from vehicle): C.W. - left hand assembly
C.C.W. - right hand assembly.
Underside guarded for blade protection and safety.

Disc Saw Drive:
Hydraulic motor sized to match base machine pump where possible. Complete disc saw drive systems also available. Drive shaft mounted on tapered roller bearings.

Clamp Arms:
Twin sets of folding multiple tree arms. Top or bottom set may be used at operator discretion for multi-tree accumulating.

APPENDIX C

HARRICANA CIRCULAR SAW SPECIFICATIONS

The "standard" model is suitable for all excavator-type carriers having a rated bucket capacity of .6 m^3 (3/4 yd^3) or more, and having a hydraulic capacity of 180 L/min (40 gpm) at 17,000 kPa (2500 psi). The "heavy-duty" model requires a bucket capacity of .84 m^3 (1 yd^3) or more.

The following list shows the changes made on the Harricana circular saw as of August 1983 (see Fig. 12):

(1) weight reduction
(2) a 15 degree side tilt system
(3) the hydraulic motor valve has been relocated on top of saw head
(4) hydraulic hoses from the stick to the boom have been relocated
(5) modification in the brackets
(6) an improved saw blade
(7) a larger drive shaft
(8) relocation of both grab arms cylinder and grab arms
(9) new design of the bumper at the top of the saw head
(10) addition of a protective skirt

(1) Weight reduction

There are two models of the circular saw head: CS5060STA and CS5060STA-HD.

CS5060STA: the standard model; it is recommended for small size excavators such as JD693B, CAT215, Timbco hydro-buncher, etc. This model is suitable for most logging conditions in eastern Canada.

Total weight of this unit is 200 kg heavier than the Harricana shear head. However since the bracket is moved 15 cm further back on this version, the moment on the boom is nearly the same.

CS5060STA-HD: The heavy duty model; recommended for larger size excavators such as CAT-225-227, DROTT-50, etc. It is designed for harvesting large B.C. trees. Both units have the same cutting capacity of 20", but the CS5060STA-HD is built more sturdy to handle longer trees.

(2) Side tilt system

Both models have a side tilt system, giving them a 15 degree tilt on either side. This tilting action greatly eases working on hilly terrain and also helps in tree bunching. The tilt system consists of a hard pin and a regular bushing located inside a hard bushing. A 5" cylinder enables the tilting action.

(3) Valve

The hydraulic main valve has been relocated to the top of the saw head frame. This new location besides giving easier access to the valve itself, has reduced the number of hydraulic hoses going from the toom to the head. It takes 5 hoses now, compared to 9 previously. This does not include the side tilt hoses which are routed differently.

(4) Hydraulic hoses

The five (5) hydraulic hoses are located on one side of the stick boom and go directly to the saw head valves and motor. This prevents those hoses from touching the ground or the brackets. This feature will help prolong the life of those hoses. Furthermore, they are well wrapped and protected by a guard (see photos).

(5) Boom adaptor

The boom adaptor (or "lifting bracket") has been re-designed so the saw head is 15 cm nearer the machine. This contributes greatly to the machine stability at all time.

(6) Saw blade

Following many tests on different sites, weather and tree species, an alloy steel blade 12.7 mm thick, having 36 teeth, with centre rakers is offered as the standard saw blade. This combination has given the best results so far. It saws more easily and lasts longer than other blades tested. Also, it is easy to rebuild.

(7) Drive shaft

Following problems with the drive shaft on B.C. units, larger shafts were installed.

(8) Grab arms

To retain trees more firmly after the cut, the grab arms have been redesigned in a more round shape. Also, the grab arm cylinders are now placed differently to ensure a tighter grip on the trees.

(9) Tree rest

The tree rest at the top of the saw head has been redesigned in a rounder shape. It has been placed farther back where it can serves as a point of rest only.

(10) Protective skirt

To satisfy the B.C. Workman's Compensation Board, rubber belting was added to the steel skirt behind the saw head.

APPENDIX D
DENIS SJ-24 TWIN SAW FELLING HEAD
SPECIFICATIONS

The Denis concept

We use two smaller saws rather than one big one, because with the same thickness of saw

— A 24" saw is only a quarter of the weight of a 48" saw.

— The same ratio applies to the power requirements, the larger saw requires four times more power.

— The strength of the smaller saw is at least five times greater than the larger one.

The end result

A lighter felling head, easy to maintain and ease of saw change at lower cost.

A great combination: less waste and lower fuel consumption.

To operate

— Drive up to the tree

— Hold the tree. You are sure with automatic lock to hold retaining arms closed.

— Bring the saws forward
As soon as the tree is cut and the operator lets go of the control lever the saws automatically retracts.

— Lay down the tree.

Principal specifications

HYDRAULIC MOTORS: Vane type with cartridge type replaceable rotor mounted in series with safety valve.

SAWS: Available with replaceable or fixed teeth, 5 bolts mounting flange, can be changed in five minutes.

HYDRAULIC SYSTEM: Modular type controls, any section can be changed independently of other section.

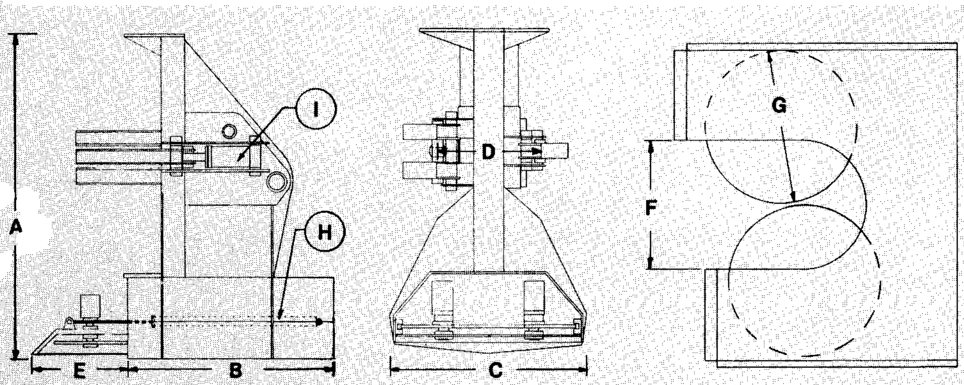
HYDRAULIC CYLINDERS: Bolted head type, positive seals, hardened rods, surface chrome .002 — Made by Denis.

NOTE: Accumulator and side tilt head available as optional extra.

Dimensions (in inches):

A: 85"
B: 55.750"
C: 52"
D: 31"
E: 26.25"
F: 19.5"
G: 24.32"
H: 2.5" bore, stroke 30"
I: 4" x 6.375"

Weights: 3,400 pd to 3,800, according to options requested.



In keeping with a policy of continuous improvement specifications are subject to change without notice.

équipements denis inc. Ste-Rosalie, Québec Tél.: (514) 799-5591 Télex: 05-830501

APPENDIX E

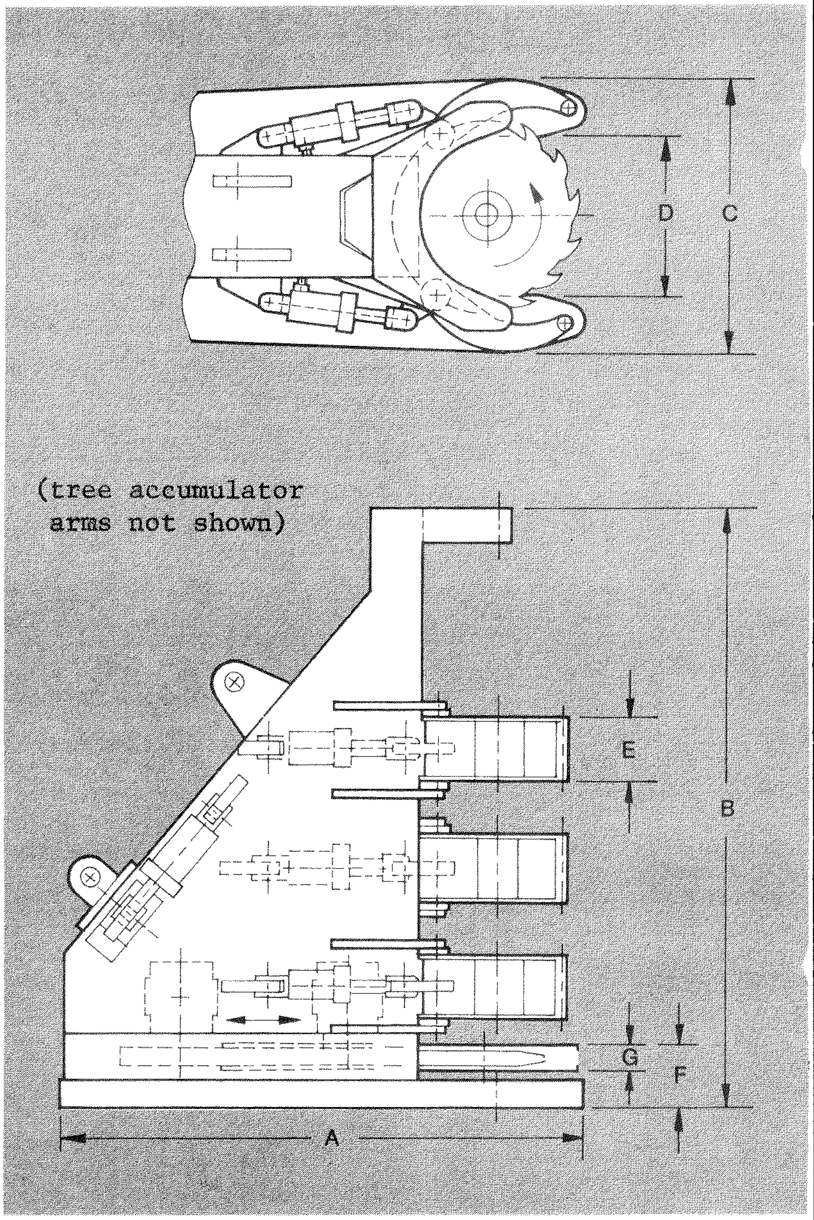
BOREAL DD-20 DOUBLE-DECK SAW HEAD

SPECIFICATIONS

BOREAL DD20 DOUBLE-DECK FELLER SAW

Designed to quickly and cleanly cut trees up to 20″ diameter without butt damage, the Boreal Double-Deck Feller Saw can be easily mounted on most small excavators and many front-end loaders. It's features include:

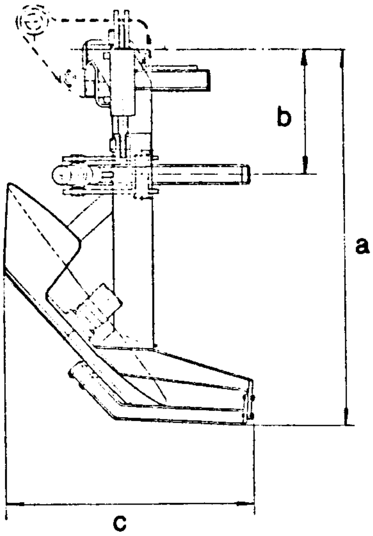
- *Lightweight – 2490 lbs. approx. (1129 kg approx.)*
- *Saws trees up to 20″ diameter (508 mm)*
- *Two circular stacked blades. No jamming.*
- *Blade speed –* 2000 rpm
- *40 h.p. hydraulic motor*
- *Pressure – 60 gpm – 2500 psi (adjustable)*
- *4-way tilt (15° each side)*
- *Retractable saw carriage for added safety*
- *Electro-hydraulic valve connection (two hoses, 1 cable)*
- *Fits low/high pressure units*
- *Accumulator attachment available as an option.*
- *Special, short/lightweight boom attachments available as extra.*



Model	Capacity	A	B	C	D	E	F	G
DD20	20″ dia.	65″	84″	34″	20″	8″	8 1/8″	3 3/4″
	508 mm	1650 mm	2100 mm	863 mm	508 mm	203 mm	206 mm	95 mm

BORÉAL HYDRAULIC EQUIPMENT INC.
29 - 8E AVE. EST, P.O. BOX 276
MACAMIC, QUEBEC JOZ 2SO
TEL: 819-782-4671 TELEX: 057-46566

APPENDIX F
LOKOMO L450 CONE SAW
SPECIFICATIONS



	L450
Max. Felling Diameter	18" (450mm)
Max. Tilting	± 15°
Weight (approx.)	1764 lbs (800kg)
Number of Grapples	1
Number of Accumulator Arms	1
Cutting Device	Circle Cone Saw 0.3" (8mm)
Number of Hydraulic Motors	3
Dimensions:	
Height	
Overall (a)	76.8" (1950mm)
Clamp arm to top (b)	25.6" (650mm)
Width (c)	51.2" (1300mm)

Hydraulic Requirements

Grapple Arms
-max. pressure 3000 psi (21MPa)
-safety pressure relief valve setting 3000 psi (21MPa)

Tilting
-max. pressure 3000 psi (21MPa)
-safety pressure relief valve in both directions 3000 psi (21MPa)
-flow control valve for regulating speed of motion

Felling
The size of the boom felling cylinder and the joint between the felling device and the boom affect the pressures. Max. moment of the felling head is as follows:

	L450
Felling Direction	3084 ft lbs (45000Nm)
Vertically	4112 ft lbs (60000Nm)

The device must have a safety pressure relief valve in both directions.

Cutting
-max. pressure 3000 psi (21MPa)
-device can be rotated in both directions
-safety pressure relief valve is not necessary

All specifications are subject to change without notice.

Distributor for North America
starting January, 1984 is
Équipement Denis Inc.
Ste. Rosalie, Qué.
(514) 799-5591

FORREX, INC.
A Rauma-Repola Company
425 U S 49 SOUTH, RT 6
JACKSON
MISSISSIPPI 39208
U S A
PHONE (601) 939-5683
TELEX 585 334 FORREX INC

Cutting Cycle Times

in seconds · with flow of 66 gpm (250 L/min)

Diameters	L450
8" (200mm)	1.8
12" (300mm)	2.5
16" (400mm)	3.2
18" (450mm)	3.5
20" (500mm)	—
24" (600mm)	—

APPENDIX G

DEFINITIONS OF MACHINE TIME ELEMENTS & FORMULAS

SCHEDULED MACHINE TIME (or HOURS, SMH): Nominal statement of intent for regular machine activity (e.g. 8-hour shift, 9-hour shift). It usually corresponds to operator's paid on-job time.

OVERTIME: The hours of productive work, service and repair carried on outside usual shift hours.

TOTAL MACHINE TIME: The sum of Scheduled Machine Time and Overtime. It is the total time associated with the machine for a given shift.

PRODUCTIVE MACHINE TIME (or PRODUCTIVE MACHINE HOURS, PMH): That part of Total Machine Time during which the machine is performing its primary function (for a delimber it is the time during which it is delimbing).

ACTIVE REPAIRS: Repair is mending or replacement of part(s) due to failure or malfunction. It also includes diagnostic time, modifications and improvements to the machine.

SERVICE: Service is fuelling, etc., and preventive maintenance performed to retain the machine in satisfactory operational condition.

DELAY: That part of Scheduled Machine Time during which the machine is not performing its primary function for reasons other than active maintenance. Delay time is divided into:

NON-PRODUCTIVE OPERATING TIME: That part of Scheduled Machine Time during which the machine's engine is running but the machine is doing something other than its primary function.

WAITING FOR MECHANIC(S): Period of in-shift time during which the machine is broken down and is not under repair due to the unavailability of mechanic(s).

WAITING FOR PART(S): Period of in-shift time during which the machine is broken down and is not under repair due to the unavailability of part(s).

MISCELLANEOUS DELAY: The unexplained difference between Total Machine Time and the sum of Productive Machine Time, Active Repairs, Service, Non-Productive Operating Time, Waiting For Mechanic(s), and Waiting For Part(s).

$$\text{Utilization} = \frac{\text{PMH (In Shift)}}{\text{SMH}} \times 100$$

$$\text{Total Time Utilization} = \frac{\text{PMH (In Shift and Outside of Shift)}}{\text{SMH + Overtime}} \times 100$$

$$\text{Mechanical Availability} = \frac{\text{PMH}}{\text{PMH + Repairs + Service}} \times 100$$

(PMH, Repairs and Service Include both in- and out-of-shift activities)

$$\text{CPPA Availability} = \frac{\text{SMH - (Repair + Service + Wait (Parts + Mechanic))}}{\text{SMH}} \times 100$$

(Repair and Service includes only in-shift)

PMH = Productive machine hours
SMH = Sceduled machine hours

CPPA Availability, by definition, is influenced not only by machine characteristics but also by operational factors (i.e. waiting for parts, or waiting for mechanic). Mechanical Availability, by definition, excludes these operational factors.

For details regarding definitions of machine time elements and data collection procedures, refer to:

M.P. Folkema, P. Giguère, and E. Heidersdorf. Shift level availability and productivity: revised manual for collecting and reporting field data. For. Eng. Res. Inst. Can. 1981.

APPENDIX H

CONVERSION TABLE

1 cm	1 centimetre	:	0.39 inch
1 m	1 metre	:	3.28 feet
1 km	1 kilometre	:	0.62 mile
1 m^3	1 cubic metre	:	0.353 cunit
1 L	1 litre	:	0.22 Imperial gallon
		:	0.26 American gallon
1 L/s	1 litre per second	:	13.20 Imperial gallons per minute
		:	15.85 American gallons per minute
1 kg	1 kilogram	:	2.20 pounds
1 kW	1 kilowatt	:	1.34 horse-power
		:	3,425 BTU
1 kPa	1 kilopascal	:	0.145 pounds per square inch
1 N/m	1 newton per metre	:	0.0685 pound-force per foot
^oC	degree Celsius	:	$\frac{5}{9}$ (^oF-32)