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

The Development of a Climbing Tree Delimber/Debarker

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PREFACE

The Pacific Forest Research Centre (PFRC), operated by the Canadian Forestry Service in Victoria, B.C., has been working on the problem of pine bark beetle infestation for many years. Their considerations led to bark removal from infested trees as a possible means of beetle population growth control.

In 1982, they contracted with the Forest Engineering Research Institute of Canada (FERIC) to develop a suitable machine to economically and effectively remove bark from infested standing lodgepole pine trees.

Drs. H.S. Whitney and L. Safranyik of PFRC were both very helpful in supplying biological data, arranging field trips to test the prototype machines and for providing overall supervision of the project.

The writer's thanks also go to Mr. Curt Bonn of Pro West Engineering Ltd. for his work in building and testing both prototypes and to Professor J. Walters who permitted numerous climbing and debarking tests to be conducted at the University of British Columbia Research Forest at Maple Ridge, B.C.

AUTHOR

Don Moulson graduated from the University of British Columbia in 1949 in mechanical engineering and became a registered professional engineer in 1956. He worked on the design, development and manufacture of chain saws; steel mills; and elevators during his industrial career.

In April 1977 he joined FERIC and worked on the design and development of new techniques and equipment for the logging industry such as feller directors, feller bunchers and silvicultural equipment.

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SUMMARY

In British Columbia, Alberta and the western United States, lodgepole pine trees are being killed in large numbers by the mountain pine bark beetle. One approach in controlling these insects is to remove the bark from infested trees so that the beetle larvae are either killed mechanically or are subject to lethal temperature variation, starvation or predation.

In the search for equipment that could remove the bark from standing trees, small European climbing and debarking machines were investigated and tested. From this beginning, a larger machine (suitable for Canadian trees) was developed.

This report gives the original design criteria and describes how the machine evolved through two stages to the present working prototype. This prototype uses a standard chain saw engine as the power source and hydraulics as the means of driving the wheels, saw and debarker. The use of hydraulics also allows a more sophisticated control system.

In operation, the machine is placed on the tree. It climbs the tree and removes the branches. At a predetermined height, the machine reverses direction and activates the debarker which removes the bark on the trip down.

Performance figures and costs are estimated from the field tests to indicate the cost effectiveness of this approach to beetle control. Other possible uses for this machine such as a portable hydraulic power source are discussed.

SOMMAIRE

Un très grand nombre de pins lodgepole sont détruits par le dendroctone du pin ponderosa en Colombie-Britanique, en Alberta et dans l'ouest des Etats-Unis. Une façon de contrôler ces insectes est d'enlever l'écorce des arbres infestés de façon à tuer mécaniquement les larves de dendroctones ou de les soumettre à des variations létales de température, à la famine ou à la prédation.

A la recherche d'équipement pouvant écorcer les arbres debouts, des petites écorceuses grimpantes européennes furent étudiées et mises à l'essai. Suite à ces études une plus grosse machine fut développée pour convenir à la taille des arbres canadiens.

Ce rapport donne les critères de conception originale de la machine et décrit son évolution à travers deux stages pour obtenir le présent prototype en fonction. Ce prototype utilise un moteur conventionnel de scie-à-chaine comme source de puissance et l'hydraulique comme moyen d'entrainement des roues, de la scie et de l'écorceuse. L'utilisation de l'hydraulique permet aussi un contrôle plus sophistiqué du system.

Pour mettre la machine en opération, on la place sur un arbre. Elle grimpe ainsi sur l'arbre en enlevant les branches. A une hauteur fixée au préalable, la machine rebrousse chemin en activant l'écorceuse qui enlève l'écorce jusqu'au bas de l'arbre.

Les données sur la performance et les coûts sont évaluées à partir des essais sur le terrain afin de démontrer les coûts effectifs de cette méthode de contrôle du dendroctone. D'autres utilisations possibles de la machine comme source de puissance hydraulique portative sont aussi discutées.

INTRODUCTION

The mature lodgepole pine forests of B.C. are being destroyed by a serious infestation of pine bark beetles. The causes of the infestation and the economic effects are discussed in several reports by the PFRC and the United States Forest Service.* Suffice it to say here that the infestation is widespread and the economic impact is very great.

The beetles bore into the bark and create vertical galleries where they lay their eggs. Upon hatching, the larvae eat through the cambium layer horizontally, leading to the death of the host tree. PFRC has been investigating methods of beetle control for some time. Such control methods as poisons, encapsulation, burning, and manual and explosive bark removal have all been tried and found unsatisfactory either because of cost, environmental unacceptability, or ineffectiveness. Early in 1981, the idea of mechanical bark removal for standing trees was considered and a Swiss machine of the 1960's, locally named a "Tree Monkey", was recalled. The Swiss machine, made by the Meier Company, was obtained in September 1981 and FERIC was approached by PFRC to test it and assist in the evaluation. These tests proceeded during late 1981 at Riske Creek and were successful enough to encourage further work in mechanical bark removal.

The Swiss designed machine (Figure 1) had a practical tree diameter range of 15 cm (6 inches) to 25 cm (10 inches) which is too small for infested B.C. pines. As well, the debarker head did not follow contour changes and tended to remove bark unevenly. The machine also lacked traction for climbing while sawing off branches and used all European components which made the supply of spare parts difficult.

It was therefore agreed that a completely new design for B.C. conditions was needed. The author visited the Meier Company of Switzerland, a manufacturer of "Tree Monkeys", to determine if they had existing machines or designs to suit the present purpose. Discussions were held regarding existing patents, parts and technical help. They did not currently have any machines directly applicable but offered co-operation, the supply of special parts, and any relevant technical help. Consequently, a project was initiated to determine the required specifications for Canadian application and to develop suitable hardware to meet these specifications. This paper describes the procedure followed.

EARLY CONSIDERATIONS

Specifying machine requirements was difficult as there was little local experience with standing tree bark removal procedures and equipment. In addition, the objectives and operating conditions were different than those governing the earlier Swiss design. For instance, the majority of infested lodgepole pine trees range in size

*See References.

Figure 1. Meier Machine.

from 15 cm (6 inches) to 50 cm (20 inches) DBH and it was not certain if this range could be accommodated by one machine size. Thus, the early specifications were a combination of what the PFRC considered entomologically desirable and what was thought might be mechanically possible. In addition, such details as the number of driving wheels; how to obtain traction on frozen and unfrozen bark; ways to handle variations in tree shape; peripheral speed; debarker design for all types of lodgepole pine bark; methods of cutting larger limbs (up to 10 cm); and the division of power between climbing, sawing and debarking had to be resolved. The specifications were written in fairly general terms and the work proceeded.

Design of the first machine, which became known as Tree Saw I (T.S. I), began in July 1982 and had the following objectives:

- desired machine capacity 15 cm (6 inches) to 51 cm (20 inches) DBH;

- as light as possible without using exotic materials which would require special repair techniques;

- use of components that are readily obtainable - particularly in logging areas;

- climbing height to 15 m (50 feet);

- machine operable by non-mechanical crews; and

- bark removal so that beetles could not survive under any remaining patches.

DESIGN OF TREE SAW I

One of the main design problems was the determination of the power requirements for climbing, sawing and debarking. The total power for the Tree Monkey was known but the division between functions was not. Tests were carried out at the University of British Columbia Research Forest at Maple Ridge, B.C. to determine the torque required to climb. With this value, as well as the climbing speed and total power available, it was possible to estimate the individual maximum power requirements for the various functions.

Another area which required considerable design attention was the number and type of driving wheels. The Tree Monkey used four small pneumatic-tired wheels with chains on the lower two (Figure 2). The

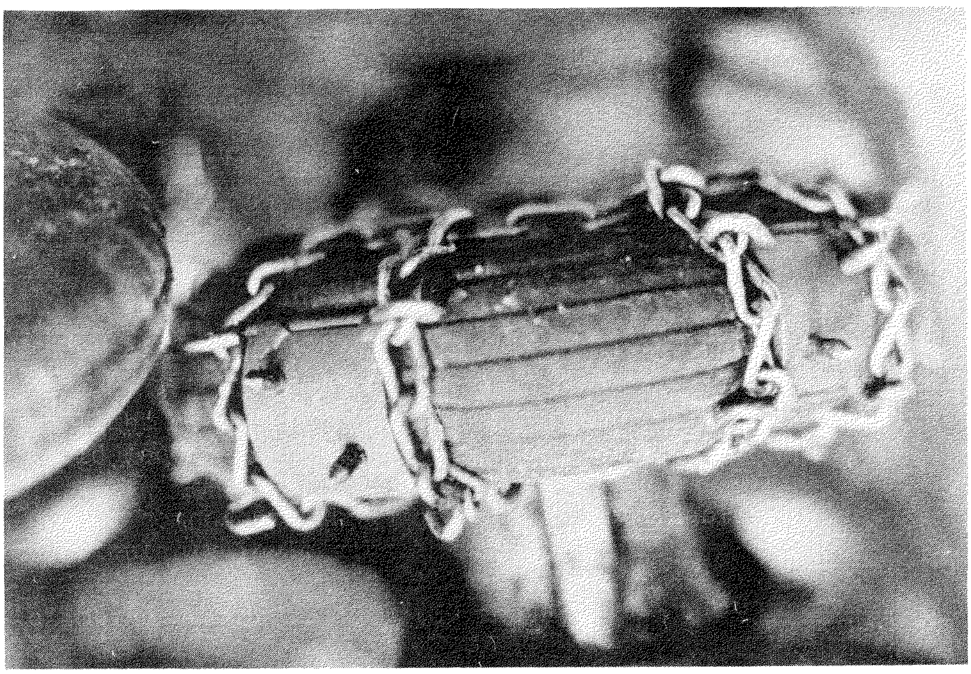

Figure 2. Meier Machine Showing Pneumatic Tires Equipped with Chains for Added Traction.

pneumatic tires provided some flexibility to accommodate taper and shape variations. However, they were badly overloaded and often deflated from pinching or separated from the rim. The only locally available pneumatic wheels of adequate capacity were 25.4 cm (10 inches) to 30 cm (12 inches) in diameter and were heavy. They would have been most difficult to fit into a light, compact machine design. Therefore, small spiked wheels of cast aluminum were chosen for the drivers and similar non-spiked wheels for the idlers of T.S. I.

Tests with the Tree Monkey had indicated that only two bottom drive wheels were necessary. This was also the opinion of the Swiss manufacturers. The use of two drive wheels would eliminate complexity and weight so it was decided to proceed with two bottom drivers with provision for adding one at the top if necessary.

Requirements for the prime power source were: a high power/weight ratio, compactness, and easy serviceability in logging areas. This suggested a chain saw power head. After considerable investigation, the Husqvarna 181 power head was chosen for T.S. I.

The Tree Monkey was fully mechanical and required complex gear drives because of the different RPMs, angle drives, and reversing features. A similar drive could have been used in the new design but with the larger capacity and power it was viewed with concern. Also, remote control was a consideration in the future and this would require electric controls. Therefore, manifolded, miniature electro-hydraulics were chosen over mechanical systems. It was felt that this would make it simpler to obtain the speeds, torques, and control required.

Since the Husqvarna saw power head chosen for T.S. I ran at 9500 RPM and the pump at 4500 RPM maximum, a drive reduction was required. Two, small section V-belts were selected as this minimized alignment problems and allowed quick exchange of power heads if needed.

The use of a minimum amount of hydraulic oil was considered desirable because of the weight and size restrictions. This, however, may have led to oil heating problems. The rate of hydraulic heat generation was not clearly known, so it was decided that particular care should be taken to cool the oil by routing the return flow through part of the tubular machine frame and an aluminum reservoir should be used.

A 12 volt DC system was chosen as the solenoids are smaller than 6 volt and more common than 24 volt solenoids. Also, 12 volt generators were thought to be readily available from motorcycles or outboards. This proved to be incorrect as most of these modern machines have their generators as integral components. A 12 volt, 9 amp generator was finally found on an older outboard and was run by friction from the back of a V-belt.

The peripheral speed of the machine on the tree was set at 13 cm (5 inches) per second which was slightly less than the speed of the Swiss machine. This was still too fast an entry speed for sawing large branches with limited power so a pressure switch was connected into the saw's hydraulic circuit which reversed the drive wheels briefly, backing the saw out of a cut, and allowing the RPM to rebuild.

A timer, with double throw contacts, activated the up direction and the saw during ascent. Upon time expiry, the timer reversed the directional valve for descent, deactivated the saw, and activated the debarker.

Considerable layout and geometry went into the frame. It was very difficult to obtain proper clamping of the machine to the tree through the entire size range. This was finally achieved by mounting the idler wheels on jointed arms but this added weight and complexity to the machine (Figure 3).

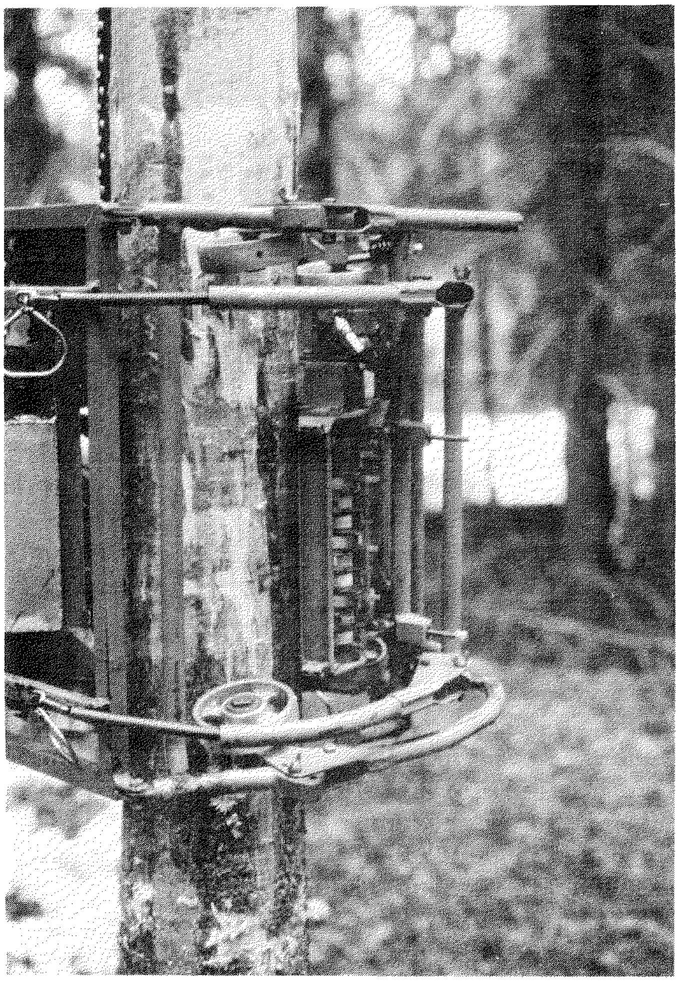

Figure 3. T.S. I Showing Jointed Arms.

The saw bar and chain ran between the two top wheels of the drive section which were very close together because of the 15 cm (6 inch) minimum tree size requirement. This necessitated accurate positioning of the saw bar and a tight chain; otherwise the teeth occasionally contacted the wheels.

The Tree Monkey debarker head consisted of pairs of teeth pivoting on rotating arms mounted on a hexagonal shaft (Figure 4).

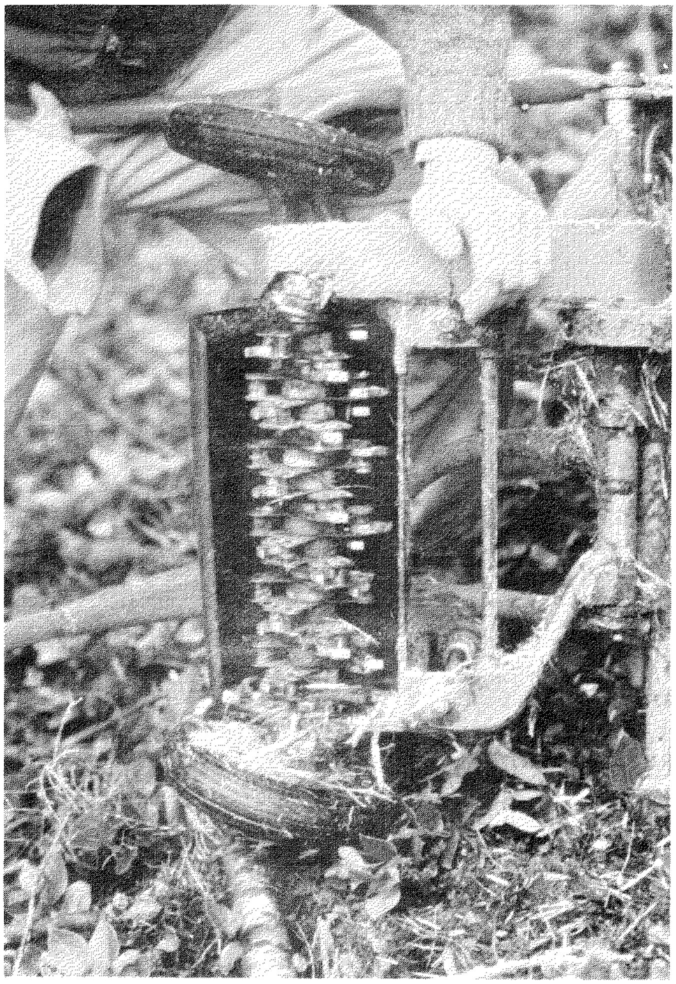

Figure 4. Tree Monkey Debarker Head.

This design had demonstrated its ability to remove even the heaviest pine bark so no thought was given to changing the method - only refining it. For instance, the arms were shortened to make the unit more compact, the RPM was increased to maintain the centrifugal force on the teeth, and the axial tooth spacing was increased to reduce the power requirement and reduce the weight. The debarker mounting was made similar to a universal joint and was spring loaded. This was done to improve its ability to follow contour changes.

Tree Saw I was ready for field tests in January 1983 (Figure 5).

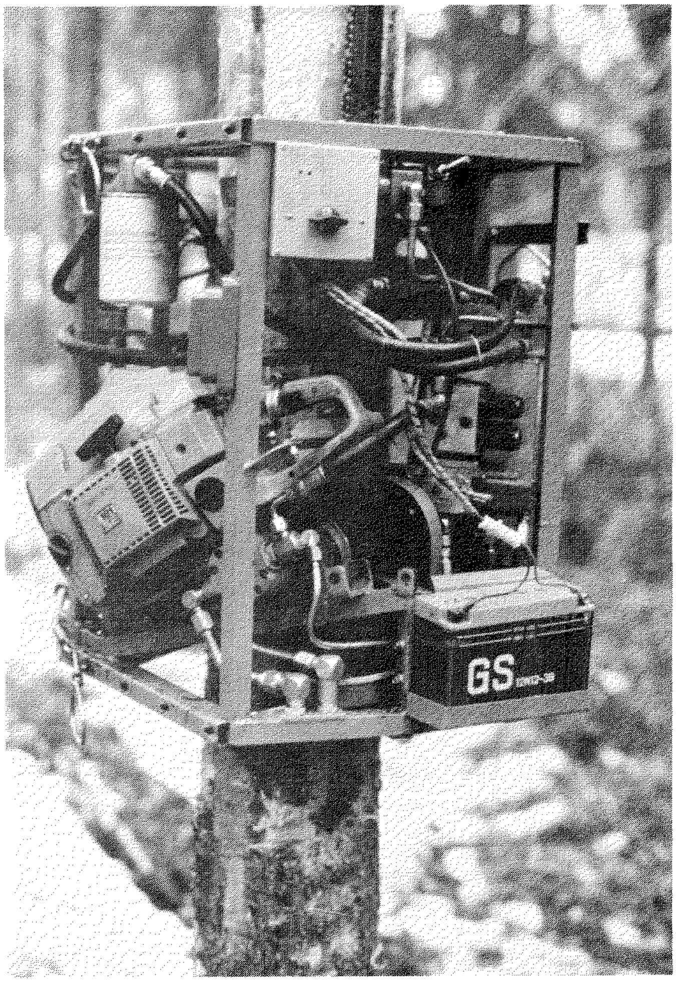

Figure 5. Tree Saw I.

Tests took place at the University of British Columbia Research Forest and later near Pemberton, B.C. The main problems which appeared during these tests were:

1. The angular spacing of the idler and driver wheels varied with tree size because the driver spacing was fixed. This allowed the machine to skew on some tree sizes - particularly when climbing.

2. All wheels were inclined to the vertical axis to produce a spiral path as the machine rotated on the tree. Because of the large tree-size range to be handled, the angle of inclination varied greatly which affected climbing rates.

3. The drive wheels used round spikes, similar to caulks, for traction. These tended to tear pieces out of the tree when loaded and dig the wheel in - stopping the climb. This, of course, varied with the wood and bark condition.

4. The drive wheels were solidly mounted to the main frame and the idlers were solidly mounted to the spring-loaded gripping arms (Figure 6). Because of machine leverages, minor changes in tree shape were magnified into large movements of machine arms and frame.

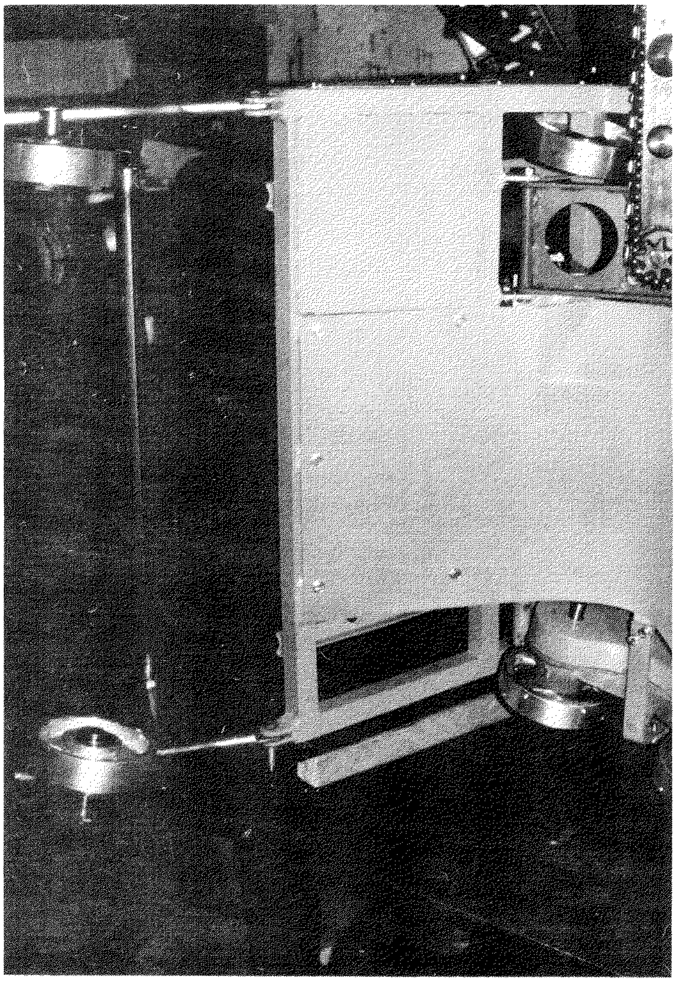

Figure 6. Tree Saw I Drive Wheels and Idler Mounting.

5. The aluminum hydraulic tank and its connections were prone to leakage.

6. Even with the jointed arms, the machine could not handle the desired diameter range. It managed from 21.6 cm (8 1/2 inches) to about 48 cm (19 inches) DBH.

7. The jointed arms, necessary to extend the size range, required the operators to estimate each tree size and make an appropriate adjustment before attachment. This was acceptable in an experimental machine but would not be satisfactory for general use.

8. The 12 volt supply from the generator proved erratic without regulation as the RPM varied too much. It was replaced by a 12 volt battery during the tests.

ANALYSIS OF TREE SAW I PERFORMANCE

Tree Saw I tests were concluded in April 1983 and meetings were held between PFRC, the manufacturer and FERIC to assess the existing machine and determine future action. The conclusions of these meetings were that many of the Tree Saw I components were satisfactory and others could be improved with modifications. However, there were enough major changes required to suggest building a new machine using as many of the original components as possible. Also, based on the tests, it was decided that attempting to cover the full size range of possibly infested trees was not practical because of the consequent mechanical and operational complexity required. Rather, a new design should concentrate on those tree sizes most frequently infested.

As a result of the Tree Saw I experience, both PFRC and FERIC were in a much better position to describe a machine that would be biologically effective and practical to build and operate. The following were the main changes incorporated into Tree Saw II:

1. The tree diameter range was reduced from 15-51 cm (6-20 inches) to 20-36 cm (8-14 inches) DBH. This reduced range covered the majority of infested lodgepole pine trees in B.C. It also allowed the removal of jointed arms and reduced the change in the wheel inclination angle with size.

2. Four synchronized drive wheels were used. Previous test experience had shown that top drivers were necessary to counter the cutting reaction forces. Certain combinations of stem contours prevented a single top driver from being effective.

3. The drive and idler wheels were given more independent movement. This helped distribute the tractive effort more evenly and reduced arm movements.

4. Since heat generation in the hydraulic system was minimal, return oil flow through the frame and the aluminum tank were eliminated. Instead, a steel tank of reduced capacity, incorporated in the frame, was used. This also permitted the valve manifolds to be mounted on the tank top and minimized leakage.

5. The complete saw assembly was located above the top drivers. This allowed the drivers to be put in their best positions without having to consider saw clearance.

6. The 12 volt battery box and the electrical control box were incorporated in the frame.

7. It was realized that the machine was too heavy for a person to carry. Practical design modifications could not lighten it sufficiently, therefore, less emphasis was placed on weight reduction and more thought given to other means of transport.

DESIGN OF TREE SAW II

Design of the Tree Saw II commenced in June 1983 and continued through the summer.

Because of the previous difficulty in distributing tractive effort evenly, the entire drive was mounted on a frame and gimballed horizontally. In addition, a track drive using modified roller chain was incorporated (Figure 7). All the idlers were independently sprung to help maintain load on the drive and reduce clamp arm movement.

In addition to the seven points previously listed, a number of smaller improvements were made:

- the frame was given a flat bottom so it was stable for transport;
- the debarker was sprung differently to allow more movement;
- the saw bracket was adjustable so the approach angle of the saw to the branches could be varied during tests;
- the electrical control box was made more accessible;
- the valve manifolds were mounted on a ground plate to minimize leakage;
- provision was made for sockets as carrying handles, if required; and
- a means was devised to vary the lever arm of the gripper springs.

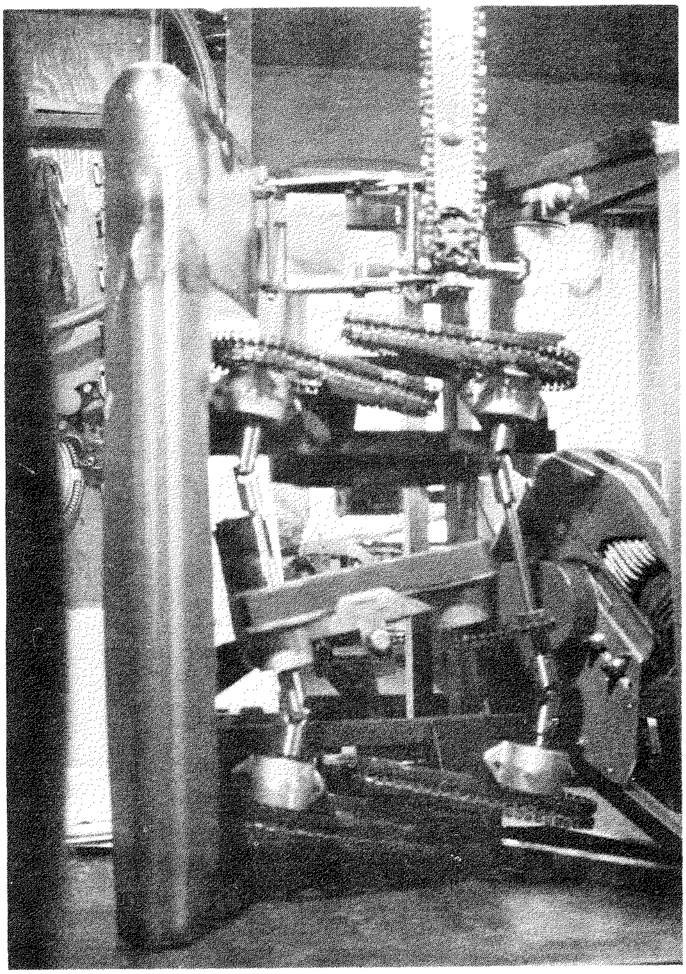

Figure 7. Gimballed Drive Frame and Tracks.
(Courtesy of Dr. H.S. Whitney, PFRC)

FIELD TESTING TREE SAW II

The initial testing of Tree Saw II was done at the University of British Columbia Research Forest during November 1983. Considerable time was spent testing the track drives on various types of trees but, eventually, the links themselves showed signs of failure. Rather than develop special chain, the track drive was abandoned and replaced with coarsely-toothed star wheels. This initially caused inclination angle problems and required several modifications to resolve the problem.

The gimballed drive and independent idler suspension appeared satisfactory. Also, during this time, both the electrical and hydraulic systems performed well.

One cause for concern was the fact that all the tests had been conducted during the rainy season on coastal hemlock trees. Undoubtedly, the wet bark on these trees had very different characteristics than frozen lodgepole pine bark in the Interior dry belt. It was therefore decided that, even though the machine was not climbing to design requirements, no more could be learned until tests were done on pine trees - preferably frozen. Penetration of tractive spikes into frozen bark had been an unknown from the outset. Therefore, in early December 1983, PFRC, FERIC and manufacturer's personnel took the machine to Penticton, B.C. for further tests (Figure 8). They were conducted approximately 15 km east of town at 1200 m elevation. The snow was about 30 cm deep and the temperature was -10 to -20 degrees

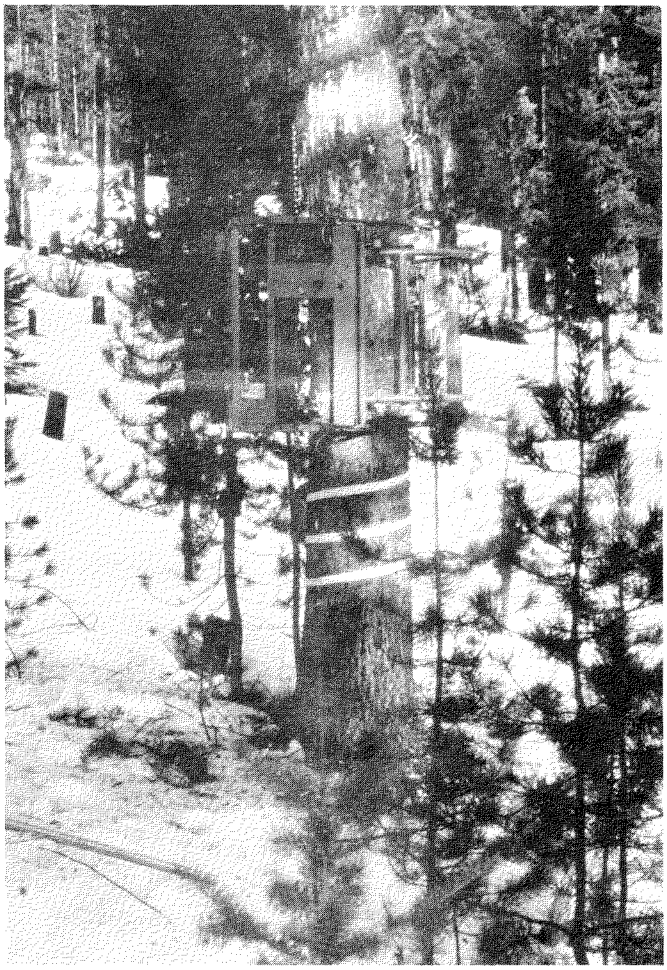

Figure 8. Tree Saw II Operating on a 39 cm (15 1/2 inch) DBH Tree Near Penticton, B.C.

Celsius. This was the machine's first exposure to cold weather and frozen trees. Concern was felt for the battery drain, valve shifting and oil viscosity but no problems arose. However, some difficulties appeared with climbing rates. Field sharpening the drive wheel teeth and increasing the drive wheel inclination overcame much of this. Neither the branch sawing nor the debarking presented any problems. The machine was tolerant of contour changes and the drive wheels did not gouge the wood. After two days of moderately successful testing, the machine was brought back to Vancouver where further minor changes were made to the wheel inclination angles and the suspension springing.

In February 1984, the machine was again taken to Penticton and tested over a three-day period - subjecting it to as many variables as possible. Conditions were similar to those of the previous tests, except the temperature which was now 0 to 5 degrees Celsius. During the tests, Tree Saw II climbed successfully on measured trees from 18 cm (7 inches) to 39 cm (15 1/2 inches) DBH. Above the design size of 36 cm (14 inches), the gripper arms did bear on the tree trunk and the debarker produced a barberpole effect (Figure 8). The vertical climbing rate was 2.9 RPM (9 1/2 FPM) of running time. Branches up to 7.6 cm (3 inches) were cut with the aid of the drive reversing feature. Debarking, which is the prime purpose of the machine, appeared satisfactory to the PFRC entomologists although two passes were occasionally required. This is a condition that further field experience will resolve, i.e. is it better to take a deeper, slower cut with the debarker at all times or debark faster and repeat where necessary? Hydraulic oil temperatures were well within normal range (i.e. after lengthy runs, oil temperature was 22 degrees Celsius (43 degrees F) above ambient).

CONCLUSIONS

With these results, the technology of the prototype Tree Saw (T.S. II) had advanced to that required by the project. It should be understood that T.S. II does not represent a fully operational machine but it does demonstrate the feasibility of the mechanical debarking approach to beetle control. More development will be required to translate the present technology level to that required for manufacturing and the eventual multiple machine use in the field.

Using the operational experience gained during the tests, preliminary economic studies were done to compare the operational costs of this type of beetle control with alternative methods.* The principal alternative, cut and burn, costs between $19.10 and $31.43 per tree, based on studies done by the B.C. Ministry of Forests.** This was later repeated, with similar results, by an independent group - D.A. Ference & Associates Ltd.

*See Appendix.

** See References.

With the Tree Saw, using 1983 cost figures and labour rates as well as operating times from field tests, the debarking costs were $12.29 to $15.24 per tree, depending on machine and crew balance. It appears that debarking standing host trees is an economically viable method of beetle infestation control relative to cut and burn methods.

The tests also showed some areas of difficulty with the basic Tree Saw which led to spin-off developments. For instance, the Tree Saw cannot remove bark in the butt flare position or around major deformities in a tree bole. This led directly to the experimental development of a small hand-held debarker for such areas. It would also be useful when beetle infestation occurs in small areas where the complete removal of bark is not required. Further, it does not appear feasible to make a standing tree debarker hand-portable for relatively long distances in the forest. This, in turn, led to the experimental development of a self-powered hydraulic unit which not only could carry a tree saw or other load, but could also provide hydraulic power for the hand-held debarker or other attachments.

It is recognized that further studies will be necessary to determine what degree of bark disruption or removal is required to obtain the desired biological result. The outcome of such studies could greatly affect design requirements of future tree saws.

There are also some suggestions being made about other uses for the Tree Saw, such as larger tree pruning and close range bole spraying. This development could not only lead to a viable means of combatting the pine bark beetle, but also to a number of other tools for the forest industry.

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APPENDIX

CLIMBING TREE SAW AND DEBARKER

ESTIMATED COSTS OF OPERATION

A. One Machine, Two Man Crew

Machine Cost:
- $14 000 cost price
- 35 weeks/year
- 5 days/week
- 3-year life

$$\frac{\$14\ 000}{3 \times 35 \times 5} = \$\ 26.65/8\text{-h day}$$

Interest on Capital:
- straight line depreciation at 15%
- zero recovery at end of life

$$\frac{\$14\ 000 \times .15}{2 \times 35 \times 5} = \$\ \ 6.00/8\text{-h day}$$

Maintenance:
- 17% of initial purchase price, per year

$$\frac{\$14\ 000 \times .17}{35 \times 5} = \$\ 13.60/8\text{-h day}$$

Expendables: (fuel, oil, chain) = $ 12.00/8-h day

Labour:
- 2-man crew, 8-hour day, $12.55/hour*

2 x 8 x $12.55	=	$200.80/8-h day
Total		$259.05/8-h day

Trees Debarked per 8-Hour Day

- Crew, 2 men at $12.55/hour
- 2 hour travelling time/day
- Crew on site 6 hours/day
- Average machine running time per tree - 8 minutes
- Average machine moving time per tree - 8 minutes
- 75% utilization

*1983 labour rate.

$$\text{Trees/8-hour day} = \frac{360 \text{ min}}{16 \text{ min/tree}} \times 0.75 = 17$$

$$\text{Cost per tree} = \frac{\$259.05}{17} = \$15.24\text{/tree}$$

NOTE: Carrier costs are not included as they are variable. Infested trees are considered to be in the same general area.

B. Two Machines, Three Man Crew

Machine Cost:

$$\frac{\$14\ 000 \times 2}{3 \times 35 \times 5} = \$\ 53.30\text{/8-h day}$$

Interest on Capital:

$$\frac{\$14\ 000 \times 2 \times .15}{2 \times 35 \times 5} = \$\ 12.00\text{/8-h day}$$

Maintenance:

$$\frac{\$14\ 000 \times 2 \times .17}{35 \times 5} = \$\ 27.20\text{/8-h day}$$

Expendables: = $ 24.00/8-h day

Labour:
- 3-man crew
  3 x 8 x $12.55* = $301.20/8-h day

Total $417.70/8-h day

Trees debarked per 8-hour day =

17 x 2 = 34

$$\text{Cost per tree} = \frac{\$417.70}{34} = \$12.29\text{/tree}$$

*1983 labour rate.