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# PRUNING MACHINE WITH A MECHANISM FOR PREVENTING BRANCH BITE

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**Abstract:** *In Japan, the typical practice in managed forests is to prune trees three times during the twenty years after tree planting and one time during the following ten years. The pruning enhances the strength of wood as a building material, reduces distortion such as warping, and promotes the production of high-quality wood without knots. The combination of pruning and thinning of trees in forests leads to an improved light environment and encourages the healthy growth of trees. During pruning, the work is sometimes interrupted because of branch bite, in which a branch bites a chain saw's guide bar because of twines being caught between branches and the like. We propose a novel pruning machine with a mechanism for preventing branch bite. The results of experiments conducted in forests show the effectiveness of the developed mechanism.*

## 1. Introduction

Japan is the world's eminent forested large country and in which 70% of the country is forest. However, because of a slump in the price of domestic lumber and the aging of workers, the management of the forests is in a difficult situation. Therefore, many forests have been neglected. Forty percent of the Japanese forests are artificial plantations. They cannot be maintained in a healthy state if there is no pruning and other care such as thinning. The condition is such that many forests have gone to ruin. Pruning, which is one of the needed cares in the artificial plantations and which is required for the production of high value-added wood without knots, should be planned and performed properly. Furthermore, pruning creates a better forest and brings greater profit. It also can limit storm and flood damage, can help maintain a living environment safe from earth and sand disasters. Furthermore, it can help to maintain biological diversity in various natural environments including rich aquatic resources. However, pruning requires a lot of manpower and is very dangerous work. It is a big problem in forestry to have a decrease in the number of employees and to have to deal with the issue of aging. The introduction of a pruning robot promises to improve productivity, reduce labor, increase labor safety, and promote the entry of younger workers by increasing the attractiveness of forestry work through mechanization. It is therefore expected to revitalize the forestry industry.

The commercially available pruning robot has a heavy weight and many other problems such as a tendency to chew branches. In the research and development on pruning robots (Yamada et al., 2004; Takeuchi et al. 2009), measures for preventing branch bites have not yet been examined. As one of the measures to address these problems, a lightweight and high speed pruning robot is being developed (Kawasaki et al., 2008; Chonnaparamutt and Kawasaki, 2009a; Chonnaparamutt and Kawasaki, 2009b). The pruning robot has a chainsaw type cutting machine and cuts a branch at spiral climbing, in which the pruning robot turns around a timber. In this branch cutting approach, it is required to solve the branch bite for efficient pruning work. Furthermore, it is required to reduce the thrust force because a contact force between the chainsaw's guide bar and the cut edge of branch increases according to cutting proceeding and it causes discontinuation of branch cutting.

This article presents a mechanical principle for preventing branch bites for the chainsaw type cutting machines and the experimental results. The basic concept is that the pruning mechanism has a sliding guide, which is attached to the chainsaw guide bar and is set to be movable linearly even if it is bitted by a branch. We call this a linear sliding guide method. Furthermore, a mechanical design to reduce the thrust force, in which the slide guide moves on a pair of circular guide rails instead of the chainsaw guide bar, is presented. We call this a circular slide guide method. In addition, the pruning work in a forest by a timberjack, who use a chainsaw with a linear slide guide, is evaluated

## 2. Pruning Work

### 2.1 Effect of pruning

Pruning can produce reasonably good quality timber (Fujimori T.,1999). A gnarl can be limited to a constant distance from a core better by pruning, which can reduce the number of gnarls that appear on the sides of finished materials and which can also decrease the diameter of knots. Of special value, it can prevent the outbreak of death knots, which cause a big fault in finished materials. Performing planned pruning can produce greater annual growth in the width of wood rings. Pruning also lets a crown shift early to the upper part of a tree and reduces the quantity of crown materials. These crown materials have a specific gravity of about 50% less than the materials below the branches, and the price of their wood is low. Therefore, pruning is effective in increasing value by increasing the material below the branches. Not only does it help in producing good quality materials; it also helps forests provide greater benefits. It increases the light in forests in early stages of growth and improves soil conservation by encouraging the growth of lower vegetation. In addition, it is useful for preventing harmful insect damage such as twig borers from invading a trunk from dead twigs and thus can prevent a forest fire from spreading to the tree crowns from the forest floor. It also facilitates work in a forest because it improves the ability to walk in a forest and increases open prospects areas.

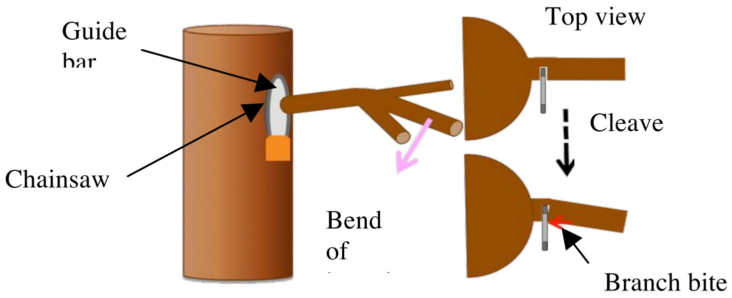
### 2.2 Automatic pruning machine

The automatic pruning machine "YAMABIKO" (made by Seirei Industry Co., LTD) is the only commercial article of its type. It has several active wheels driven by the engine and passive wheels. Its main body goes up and down in a spiral, and this cuts off a branch with a chainsaw, which is installed to comply with a tree trunk. The specifications of the cutting machine are targeted for cutting a hinoki branch with a diameter of 40 [mm], a cedar branch with a diameter of 45 [mm], and a trunk with a diameter of 150 to 300 [mm]. The length of its bar is 337 [mm], the oil tankage is 0.6 [L], and the weight is 32.8 [Kg]. It is not used very much because of its weight and branch bite problems.

## 3. Linear Slide Guide Method

### 3.1 Branch bite

A branch generally turns in various directions as it grows towards the direction of the sunlight. Therefore the center of gravity of the branch may not always bend along a branch right below. When a chainsaw cut a branch as shown in Figure 1 (a), the brunch sometimes bites a chainsaw guide bar as shown in Figure 1 (b). When such a branch bite occurs, the pruning machine can not move on a tree. It was reported (Saito T., et. al., 1991) that the branch bite occurred 0.98 times for each tree when the automatic pruning machine cut branches in a forest. This reduces pruning work efficiency remarkably because a forestry worker climbs up the tree and repairs the pruning mechanism.




(a) Pruning by chainsaw (b) Working of branch bite

**Figure 1.** Mechanism of branch bite

Table 1 shows the specifications for the weight, speed and diameter of pruning trees in the development of the pruning robot by our group. The pruning robot has a function for preventing branch bite. The cutting mechanism is configured by the chainsaw, chain running guide bar and motor drive. The design seeks to realize the following aims:

- To cut off a branch with a diameter of 50 [mm].
- To finish cutting a branch with a length of last 5 [mm] at branch bite.

**Table 1.** Target of cutting mechanism

| Greatest trunk Diameter [mm] | Greatest branch Diameter[mm] | Aim weight [kg] | Aim cutting speed [mm/s] |
|---|---|---|---|
| 350 | 50 | 3.0 | 90 |

### 3.2 Principle for preventing branch bites

A novel mechanism for preventing branch bites fundamentally has been designed. Developed mechanism consists of the chainsaw's guide bar, two covers which are attached to both sides of the guide bar, and the spacer which is installed through a spring on the guide bar and is set to be movable to a limited extent, as shown in Figure 2. When a branch bites the covers at cutting, the chainsaw can move straight because the covers and the spacer can slide on the chainsaw's guide bar. This permits us to continue cutting as shown in Figure 3. We call this a linear slide guide method for preventing branch bites.

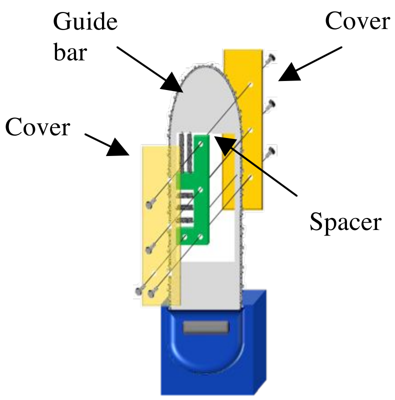
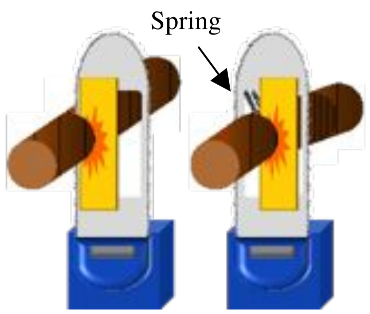



**Figure 2.** Linea slide guide method




a. When the branch bite begins
b. As the branch bite continues.

**Figure 3.** Phase diagram of the mechanism for preventing branch bites

Figure 4 shows a prototype of this principle to a chainsaw. This uses the marketing product, the electromotive chainsaw (UC121D by Makita Corporation), on which the mechanism for preventing branch bites has been installed. The movable range of the spacer is 8 [mm].

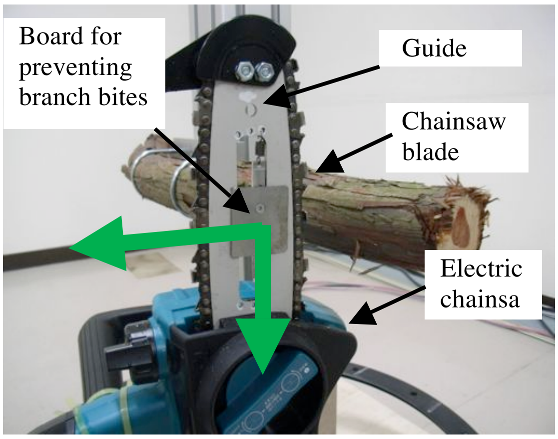



**Figure 4.** Prototype of the linea slide guide method

### 3.3 Evaluation experiment

We performed an experiment to identify the effectiveness of the principle of the mechanism for preventing branch bites. A branch with a diameter of 40 [mm] is fixed on a rectangular rod as shown in Figure 4. The pruning machine can move on a circular guide rail by the transportation mechanism, which generates the thrust force to cut branches. A diameter of cut end of the chainsaw is 250 [mm]. In the experiment, a branch is cut off until the remaining portion of the branch became 8 [mm] and is bended forcibly to generate a branch bite. Then, cutting is continued with forward speed 5 [mm/s]. The experimental results are shown in Figures 5 and Figure 6.

Figure 5 shows the motor torque of the transportation mechanism for cutting using the marketing product without the linear slide guide. After occurring the branch bite, the motor torque of the transportation mechanism increases lineally and reaches its maximum torque. Then, the cutting is stopped by the action of protection circuit. On the other hand, Figure 6 shows the motor torque of the transportation mechanism using the proposed linear slide guide for preventing branch bites. We could complete cutting with a small torque equal to or less than 40% of that shown in Figure 5 even if a branch bite occurred.

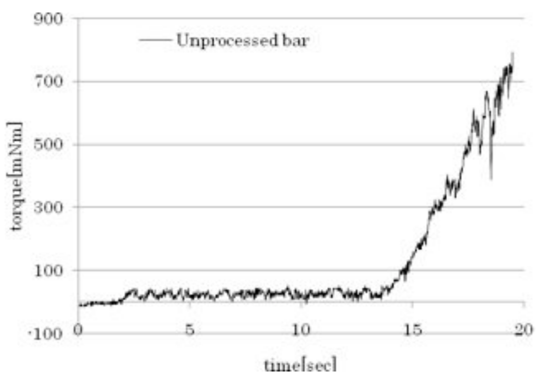



**Figure 5.** Motor torque of the transportation mechanism using marketing product chainsaw without linear slide guide

These experiment results show the effectiveness of the linear slide guide for preventing branch bites. However, larger motor torque is required as a diameter of branch is bigger and/or the diameter of cut end of chainsaw is smaller.

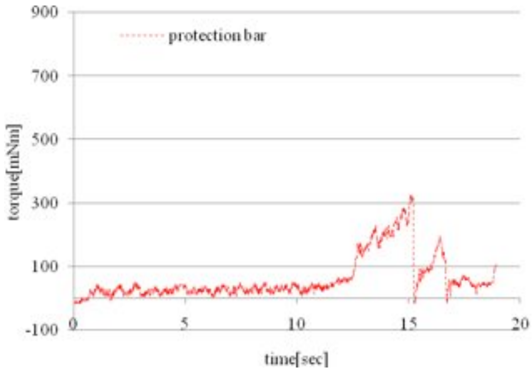
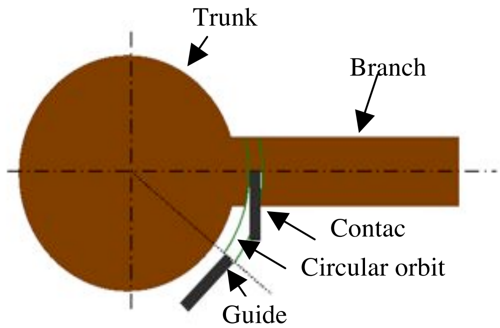



**Figure 6.** Motor torque of the transportation mechanism using a chainsaw with linear slide guide

## 4. Circular Slide Guide Method

### 4.1 Cutting problem of a circular orbit

It is usual that a timberjack cut branches using a chainsaw along straight line. The timberjack considers to prevent the branch bite. However, when an automatic pruning robot cut branches along the trunk surface, the cut end of chainsaw is a circular orbit as shown in Figure 7. This derives a contact between the chainsaw guide and the cut surface of branch as shown in Figure 8. The thrust force which is tangential direction of the circular is divided into the cutting force, which is needed to cut the branch, and the contact normal force, which is need to bent the branch. Therefore, this cutting approach is inapplicable for large size branch and/or small size circular orbit because large thrust force is required at the contact point to bend the branch.



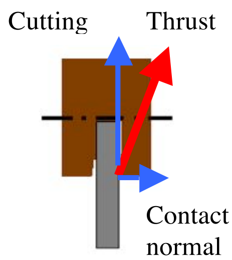




**Figure 7.** Circular orbit of the cut

**Figure 8.** Power at the time of the cut

### 4.2 Mechanism for reducing thrust force at circular orbit cut

In cutting in a circular orbit, the thrust force is needed to bend a branch even if the branch bite preventing mechanism is attached. To solve this problem, a pair of circular rails is attached to the guide bar of chainsaw as shown in Figure 9. The covers and the spacer moves along the circular rails, which diameter is set nearly to that of the circular orbit of cut end. If the both diameters are same, the normal contact force is not generated and the thrust force equals the cutting force. This mechanism contributes to reduce the thrust force and to short the remaining branch length.

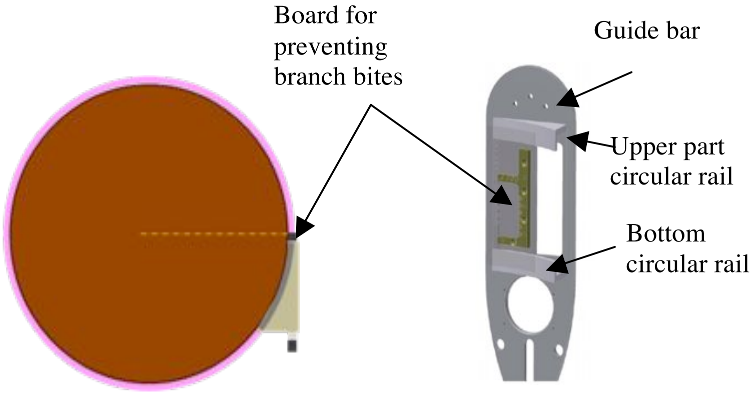



**Figure 9.** Circular slide guide method for preventing branch bites for circular orbit cuts

**4.3 Experiment of a circular orbit cut**

Experimental environment of circular orbit cutting is shown in Figure 10. A branch bite is generated by pulling the end of a branch by a weight 1.9 [kg] through a pulley. The experimental condition is shown in Table 2. Two radius of gyration of cutting are evaluated.

First, we evaluated the linear slide guide method. In case of the radius of gyration 293 [mm], the cutting machine with a linear slide guide is attached on a ringed rail. The linear slide guide for preventing branch bite functioned and the cutting is completed. However, in the case of the radius of gyration 100[mm] that are a smallest trunk radius, the pruning machine stopped at the last of 10 [mm]. This is not caused by the branch bite, but caused by the influence of the circular orbit cut. Figure 11 shows the motor torque at the case of the radius of gyration 100[mm]. The motor torque reached the maximum and the transportation mechanism stopped.

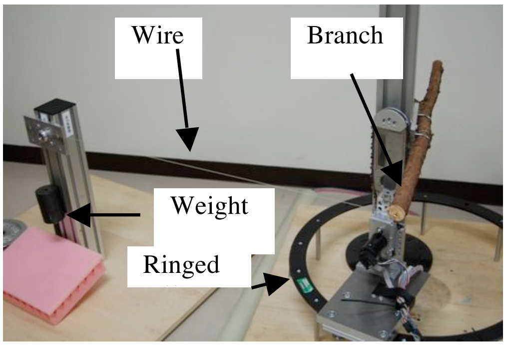



**Figure 10.** Experimental environment of circular orbit cut

**Table 2.** Experimental conditions of circular orbit cut

| Radius of gyration [mm] | Branch diameter [mm] | Weight [kg] | Forwarding speed [mm/s] |
|---|---|---|---|
| 293 | 30 | 1.9 | 5 |
| 100 | 30 | 1.9 | 5 |

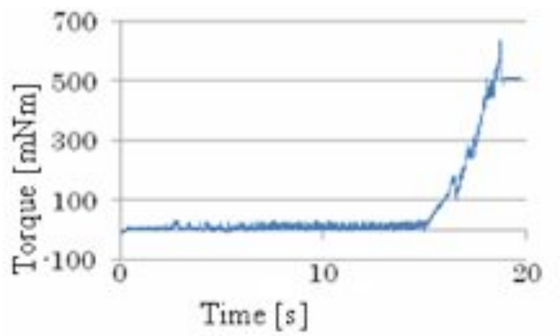



**Fig. 11.** Motor torque using a linear slide guide at radius of gyration 100 [mm]

Next, we experimented in case of the radius of gyration 100 [mm] using a circular slide guide method for reducing thrust force. The experimental condition is similar to that on the linear slide guide method. A difference is a branch diameter, which is set to 46 [mm]. Figure 12 shows the chainsaw with a circular slide guide for preventing branch bites. The cut was completed because the circular slide guide mechanism for preventing branch bites and for reducing thrust force functioned.

**Figure 12.** Chainsaw with circular slide guides for reducing thrust force

Figures 13 show the motor torque in case of the mechanism for reducing thrust force at radius of gyration 100 [mm]. The cutting could be completed by a motor torque, which was 45[mNm] before cutting and 75[mNm] during the cutting. This indicates that when a branch is cut off along the circumference of the trunk, the normal contact force is not generated and the thrust force is equal to the cut force which is constant and is depend on the forwarding speed to cut. Figure 14 (a) shows a branch bite and Figure 14 (b) shows a view from the top at pruning, which indicates completeness of cutting.

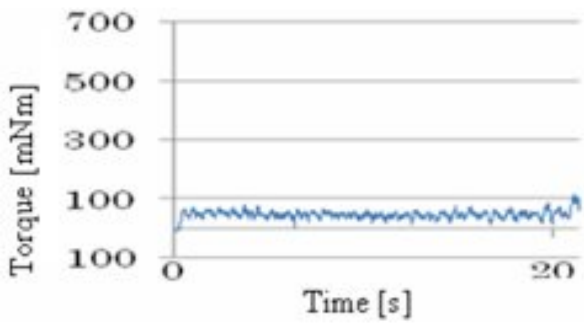
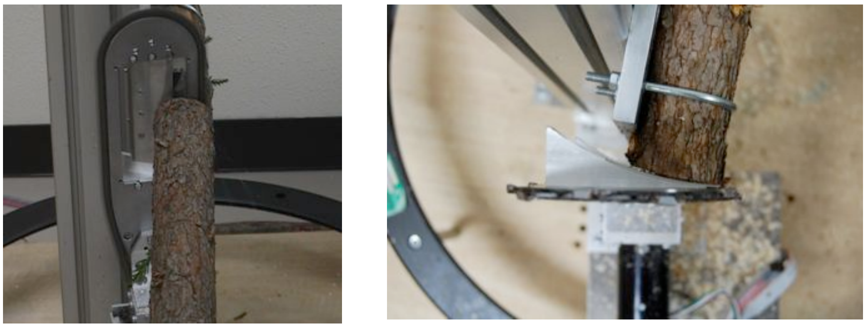



**Figure 13.** Motor torque using a circular slide guide at radius of gyration 100 [mm]



(a) State of branch bite b) View from the top at pruning

**Figure 14.** Experiment of the circular slide guide

### 5. Test in a Forest Using Engine Chainsaw

An engine chainsaw is best used for work such as pruning and cutting branches after they have been felled. Therefore, a pruning experiment with engine chainsaw was executed in a forest for evaluation of the linear slide guide method for preventing branch bites. Figure 15 shows a chainsaw whose chainsaw's guide bar is installed a linear slide guide mechanism for preventing branch bites.

In the experiment, a skilled forest worker cut branches as shown in Figure 16. The tree was a cedar of 20 from 40 years old; the branch had a diameter from 30 [mm] to 40 [mm]. To evaluate the prevention function of branch bites, the pruning was carried out purposefully from the bottom of the branch. In the results of experiment, the chainsaw without the mechanism for preventing branch was always bitted by a branch but the chainsaw with the linear slide guide mechanism succeeded the pruning. This means that a pruning robot with slide guide mechanism for preventing branch bites has a high potential for the improvement of the pruning work efficiency.

**Figure 15.** Engine chainsaw with a linear slide guide

**Figure 16.** The experiment in forest

### 6. Summary

This paper has presented a linear slide guide method for preventing branch bites, which consists of a pair of guide covers and a spacer. The spacer is set to be movable linearly on the chainsaw's guide bar at the branch bites. The effectiveness of the linear slide guide method has been demonstrated experimentally. It was pointed out that the thrust force increases when a pruning robot cuts a branch with a spiral motion. To solve this problem, the circular slide guide method was proposed. The effectiveness of this has been shown by experiment. In addition, the experiment using engine chainsaw with a linear slide guide in forest showed a high potential of pruning robot, which prevents branch bites.

We have a plan to set the slide guide mechanism to a pruning robot and to test its effect in a forest.

**Acknowledgement**

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