Study on Pruning Operation with Electric Circular Saw
Experiment of Cutting Ability and Finishing State

Kunihiko NUMATA, Toshiaki YAMAMOTO,
Kimihiko ISHIGAMI and Tetsuro SAKAI

電動丸鋸による枝打ち作業に関する研究
丸鋸歯の鋸断性能と仕上げ状態に関する試験

沼田　邦彦・山本　俊明・石上　公彦・酒井　徹朗

Abstract

We experimented the cutting ability and the finishing state of cutting surface profile according to three type teeth of electric circular saw used at present for artificial green pruning operation. The experimental factors are Saw Type (tipped saw, original saw, filed saw), Size of Twig (8mm, 12mm, 18mm), Cutting Speed (fast, slow), Species of Twig (Sugi, Hinoki), Cutting Angle (90°, 45°), and Moisture Condition of twig (dry, wet, live). We investigated these factors according to the experimental designs of orthogonal array L_{27} (3^{13}). The results are as follows; we can make cutting time shorter on cutting a twig "fast" and perpendicularly to longitudinal direction of a twig, and save cutting energy with a thin edge blade and at "fast" Cutting Speed. But on the other hand, we need to prune at "slow" Cutting Speed and perpendicularly to longitudinal direction of a twig for preventing from the defects such as hang-nails or splits on the surface of the pruned tree. As pruning operation is popularly performed in drywinter season, so it is important to pay extra attention to pruning "small" twigs, which are apt to split.

要　　旨

電動丸鋸による枝打ち作業について鋸断性能と鋸断表面の仕上がり状態を調べるために，歯形（チップドソー，鋸歯，目立て歯），枝の径（8㎜，12㎜，18㎜），鋸断速度（速，遅），枝の樹種（スギ，ヒノキ），鋸断角度（90°，45°）および枝の乾燥状態（乾，湿，生）の6因子を取り上げ，直交表L_{27}（3^{13}）に従って実験計画を組み，各因子の要因分析を行った。その結果，枝軸に直角に素早く枝打ちすることで，鋸断時間は短縮され，一方鋸断速度を“速”，刃先の厚みの薄い歯を使用することで鋸断消費エネルギーは少なくなるが，しかし鋸断表面の仕上がり状態を良くするには鋸断速度を遅く，枝軸に直角に当てる枝打ちがよい。また枝打ちは冬期の乾燥

時期が最盛期であるから，枝打ち面の割れ等を防ぐために，小さい枝を打つときは特に注意が肝要である。

1. Introduction

The pruning operation in Japan has been performed for producing timbers without knots in man-made forests of Sugi, Japanese cedar (*Cryptomeria japonica D. DON*) and Hinoki, Japanese cypress (*Chamaecyparis obtusa ENDL*), and popularized to the advantage of trading at high prices as polished logs and saw timbers on no knot surface. During this decade, many kind of auto tree-climbing/pruning machines have appeared almost in advanced private forests and the number of these machines have increased for work safety and operational efficiency according to coping with increase of older workers and higher personnel expenditure. But it has been evident that these auto tree-climbing/pruning machines give sometimes the discoloration of wood (botan zai in Japanese) or rotted parts within timbers. We choose the power circular saw for pruning machines as an object of our experiment for the reason why we can get high efficiency and little impact to artificially pruned trees, while the finishing surface profile state of trees pruned with power saws has often more defects such as sprits and hang-nails than with hatchets. We have to solve some problems of cutting surface profile according to power circular saws. Therefore we perform some experiments for investigating principal factors which affect the finishing state of surface profile with electric circular saws in order to improve the finishing state in quality.

2. Purpose of Experiment

On using circular saws in the experiments, we chose three saw types which were at present used for the artificial green pruning operation in man-made forests, and measured the cutting ability such as the consumed time and the consumed energy for cutting twigs. We asessed mainly the degree of finishing surface smooth as a criterion of good saws. In future work, we intend to investigate the occlusion which saw types make the pruned surface recover faster and well with the new timber tissue after pruning.

The circular saw of this pruning machine used in the experiment is rotated with a flexible shaft driven by an electric motor. The pruning machines with a gasoline engine instead of an electric motor are produced and popularly sold by KAAZ CUTTER Co. Ltd. in Japan. The saws used in the experiment are a tipped saw (saw type Ⅰ), an original saw without tipped teeth (saw type Ⅱ) and a saw filed with a round file (saw type Ⅲ). Saw type Ⅲ is used in pruning operation in order to enable to file circular saws as easily as circular saws of brush cutters, and on saw type Ⅲ, we investigated the performance of pruning operation at a certain private forest company in Aug. 23, 1989. Therefore we especially pay attention to the experimental results about Saw type Ⅲ.

3. Planning of Experiment

We planned the experimental designs to investigate the consumed time and the consumed energy for cutting twigs and the finishing state of cutting surface profile. We choose six factors as follows; Saw Type (factor A), Size of Twig (factor B), Cutting Speed (factor C), Species of Tree (factor D), Cutting Angle (factor E) and Moisture Condition of twig (factor F);

Factor A: Saw Type consists of three levels, "saw type Ⅰ" (tipped saw: saw diameter 105mm, blade pitch 11mm, blade thickness 1.2mm, number of blade 30), "saw type Ⅱ" (original saw before welding tipped teeth: saw diameter 105mm, blade pitch 11mm, blade thickness 0.9mm, number of blade 30) and "saw type Ⅲ" (saw filed with a round file: saw diameter 105mm, blade pitch 11mm, blade thickness 0.9mm, number of blade 30). A tooth of each saw type is shown in Fig. 1.

Factor B: Size of Twig consists of three levels, "small" (twig diameter about 8mm), "medium" (about 12mm) and "large" (about 18mm).

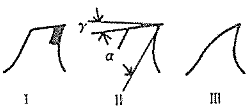

Fig. 1 A tooth of each saw type
Ⅰ: tipped saw
Ⅱ: original saw
Ⅲ: filed saw

Factor C: Cutting Speed consists of two levels, "fast" and "slow". Cutting Speed represents the speed of pushing a saw into a twig, but doesn't mean the rotation speed of a saw.

Factor D: Species of Tree consists of two levels, "Sugi" and "Hinoki".

Factor E: Cutting Angle to the longitudinal direction of a twig consists of two levels, "90°" and "45°".

Factor F: Moisture Condition consists of three levels, "dry" (natural dryness during 3 months after picking twigs out), "live" (twigs in 4 days after picking out), "wet" (soaking twigs in water a month), and "dry" and "wet" materials were picked out at a certain forest company in Aug. 23, 1989 (summer season), but "live" materials at Kamigamo experimental forest of Kyoto Univ. in Dec. 15, 1989 (winter season).

We measured the consumed time and the consumed electric power for cutting twigs by the auto pen-recoder (Yokokawa LR4100), and gauged the maximum diameter and the minimum diameter of cutting surface profile, and observed the finishing state of cutting surface profile to classify four categories: "smooth", "rough", "hang-nail" and "split".

We used the experimental designs of orthogonal array L_{27} (3^{13}) for investigating the main effects of each factor and interactions of a factor A, B and F which consist of three levels, and duplicated each experiment three times, then totally experimented 81 times.

4. Results and discussion

Fig. 2 shows the chart of the auto pen-recorder about the consumed electric power at cutting a twig with a circular saw. We mainly discuss the factorial effects which have the significance at 5% and 1% level of F-values test.

4.1 Cutting time

On considering cutting time, we will be able to assess the effect of each experimental factor relating to cutting speed how steadily an operator could control Cutting Speed under various factorial conditions subjectively, because we could not use the cutting devise with a steady speed feeder. On the other hand, we can find the factorial conditions on which effect the cutting resistance and so forth.

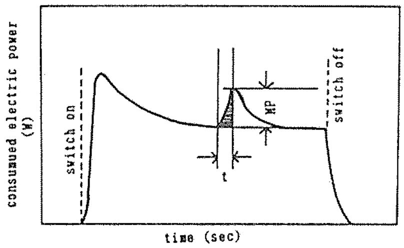

Fig. 2 Chart of the auto pen-recorder about the consumed electric power with a circular saw
t: cutting time
MP: maximum instantaneous consumed electric power

4.1.1 Main effect of Saw Type (Fig. 3.1, significance at 1% level, ρ: 3.04%), ρ shows the ratio of the net factorial variance of a main effect or an interaction to total variance.

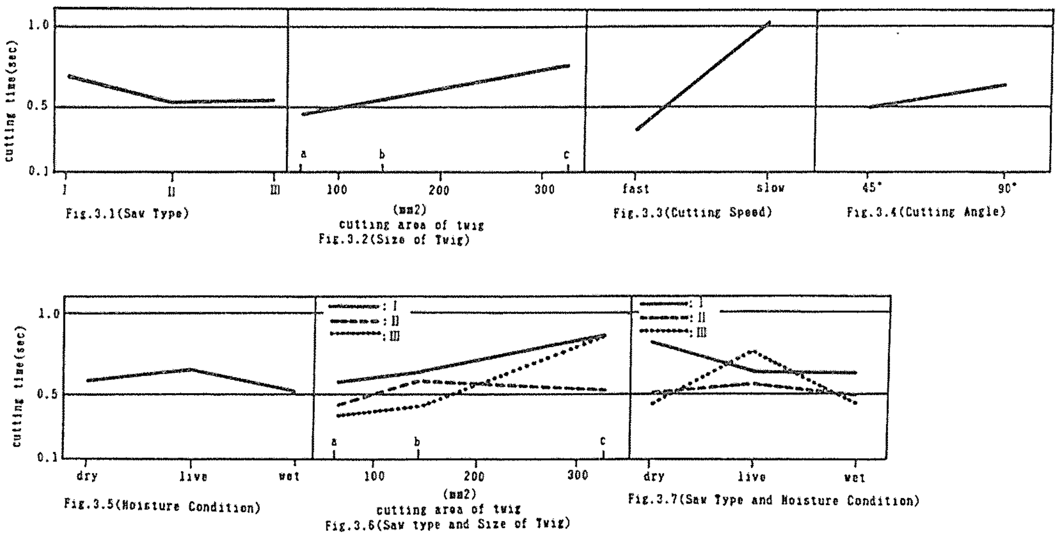

Fig. 3 Cutting time on each factorial effect

I:	tipped saw type	a:	small size of twig
II:	original saw type	b:	middle size of twig
III:	filed saw type	c:	large size of twig

Cutting time on tipped saw (saw type III) is relatively long. As the cross section width of a tipped saw edge is wider than of the others, we guess that a tipped saw receives more cutting resistance.

4.1.2 Main effect of Size of Twig (Fig. 3.2, significance at 1% level, ρ: 8.93%)

Cutting time increases in proportion to the cutting cross section area, but the difference of cutting time between "small" and "large" twig diameter with a motor power is very little; that is, Cutting time of a "large" twig diameter is less than twice time of a "small" one.

4.1.3 Main effect of Cutting Speed (Fig. 3.3, significance at 1% level, ρ: 59.11%)

The net factorial effect of Cutting Speed, which is an experimental controlling factor, occupies about 60% of total variance. Then we find that Cutting Speed in the experiment was almost completely controlled by an operator. Cutting speed under "fast" condition was about thrice as fast as under "slow" one.

4.1.4 Main effect of Species of Twig

Species of twigs between Sugi and Hinoki has no effect on cutting time at all. According to manual pruning investigations (1), it generally takes longer to prune Hinoki twigs than Sugi twigs, but as far as we discuss under this experiment with a motor power, we found to neglect the difference of cutting time between Sugi and Hinoki

4.1.5 Main effect of Cutting Angle (Fig. 3.4, significance at 1% level, ρ: 2.11%)

In the case of Cutting Angle 45°, cutting time is unexpectedly shorter than in the case of 90°. From this result, Cutting Speed is operated subjectively faster than on 90°, although the cross section area on 45° is of course larger than on 90°. We assume that in the case of Cutting Angle 45° an operator has to cut twigs in the precarious touch for pushing a circular saw to the direction on which both bending force and sliding force act and then he will be apt to grasp tightly the holder due to preventing wrong cutting operation and kick-back. Therefore we guess that the cutting on 45° gives much impact on the trees and an operator exposes himself to much danger. From these points, an operator needs to cut on Cutting Angle 90° to the longitudinal direction of twigs.

4.1.6 Main effect of Moisture Condition (Fig. 3.5, significance at 5% level, ρ: 1.40 %)

Cutting time is especially long under "live" condition. The season, the site, the ring density and the age that "live" twigs were picked out are different from the cases of the other moisture condition twigs. Then, "live" twigs are made up of the hardest wood tissue in quality under this experimental condition. According to the relation between "dry" and "wet" moisture condition, the cutting time on "dry" is longer than on "wet" condition.

4.1.7 Interaction between Saw Type and Size of Twig (Fig. 3.6, significance at 1% level, ρ: 3.68%)

The cause of interaction will be occurred in factorial combination of "saw type Ⅱ" (original saw) and "large" Size of Twig, and cutting time of this factorial combination is extremely short under large Size of Twig condition. On the original saw shown in Fig. 1, angle γ is smaller and angle α is larger than saw type Ⅲ (filed saw), and edge width is smaller than saw type Ⅰ (tipped saw). We guess that the original saws decrease cutting resistance and cutting impact on pruning trees.

4.1.8 Interaction between Saw Type and Moisture Condition (Fig. 3.7, significance at 1 % level, ρ: 3.81%)

The cause of interaction will be mainly occurred in two factorial combinations. one combination is "saw type Ⅲ" (filed saw) and "live" Moisture Condition, on which cutting time is long, and the other combination is saw type Ⅰ (tipped saw) and "dry" Moisture Condition; on which cutting time is long, too. As "live" Moisture Condition has the hardest wood in quality under this experiment, "filed saw" will receive the largest resistance and impact from the hardest wood. Under the relation between "dry" and "wet" Moisture Condition, "filed saw" is superior to the other saw types from the point of cutting time. It is important to investigate cutting ability and cutting resistance and cutting impact on the relation between filed saw types and some wood features of pruning twigs in detail.

As we discussed the significant factorial effects above, we summarize the results as follows; on Cutting Speed, "fast" level is completely controlled thrice as fast as "slow" level by an operator, and Cutting Angle 90° has to be kept at cutting twigs with a circular saw for work safety, and the last, for operational efficiency we need to pay attention to Cutting Speed "fast" on "filed saw" which is superior under the "dry" and "wet" Moisture Condition.

4.2 Consumed electric power for cutting twigs

On calculating cutting energy, we measured the triangle area of a slant line part on the chart in Fig. 1, and this area represents the consumed electric power in watt.sec. The effects of factors on the consumed electric power are similar to those on cutting time. Assuming that the consumed electric power is in proportion to cutting time, it will be reasonable to obtain the same relation on the consumed electric power as on cutting time. As we mentioned above, we explain briefly main effects and interactions of significant factors as follows.

4.2.1 Main effect of Saw Type (Fig. 4.1, significance at 5% level, ρ: 3.10%)

As we discussed cutting time on Saw Type in 4.1.1 (see Fig. 3.1), the consumed electric power of each saw type level is similar to cutting time. We point out from this factorial effect that the least power consumption is on saw type Ⅱ (original saw), which has a thin edge width.

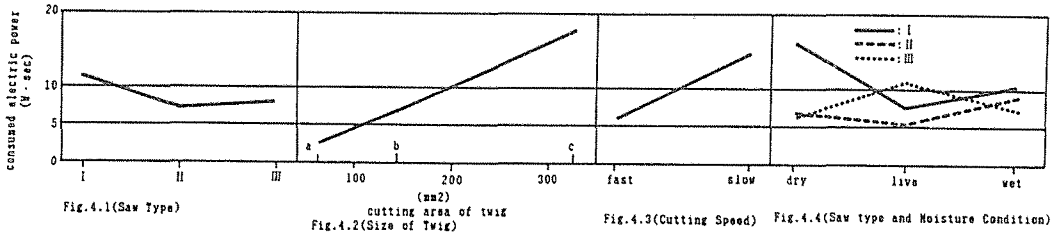

Fig. 4 Consumed electric power on each factorial effect

Ⅰ:	tipped saw type	a:	small size of twig
Ⅱ:	original saw type	b:	middle size of twig
Ⅲ:	filed saw type	c:	large size of twig

4.2.2 Main effect of Size of Twig (Fig. 4.2, significance at 1% level, ρ: 44.97%)

The consumed electric power of Size of Twig levels is similar to cutting time (see Fig. 3.2), but although the difference of cutting time between "small" and "large" twig diameter is very little, the difference on the consumed electric power is very high, and this factor's ρ occupies about 45%. We find that the consumed electric power is just in proportion to the cross section area of twigs.

4.2.3 Main effect of Cutting Speed (Fig. 4.3, significance at 1% level, ρ: 20.16%)

The consumed electric power of each Cutting Speed level is similar to cutting time (see Fig. 3.3), and the relation of the consumed electric power between "fast" and "slow" Cutting Speed is just in the adverse relation of cutting time. We can say the same result in section 4.1.3 (see Fig. 3.3).

4.2.4 Interaction between Saw Type and Moisture Condition (Fig. 4.4, significance at 1 % level, ρ: 5.19%)

The consumed electric power of combination level "tipped saw" and "dry" is especially high, and this interaction is almost similar to cutting time (see Fig. 3.7).

As we mentioned above, the consumed electric power is in the close relation with cutting time. Therefore, to economize on the consumed electric power for cutting twigs, we need to choose Cutting Speed level "fast" and Saw Type level "original saw" or "filed saw" that has a thin edge width.

At last, we briefly explain the maximum instantaneous consumed electric power (MICEP), exclusive of the consumed electric power at racing (unloading), as follows; main effect of Size of Twig on MICEP occupies about 76% of total variance, and MICEP is about 15 watt in the case of "small" twig diameter (8㎜) and about 55 watt in the case of "large" twig diameter (18㎜). These net cutting electric power level is very low in comparison with the starting consumed electric power level about 400 watt at the moment of switch on.

4.3 Finishing state of cutting surface profile

Generally evaluating the finishing state, we classify the finishing state of cutting surface into 4 categories "smooth", "rough", "hang-nail" and "split" and allocate each category following score that is weighed in proportion to the defect of the finishing state; "smooth": 0, "rough": 1, "hang-nail": 3, "split": 10. We consider the results of main effects and interactions as follows.

4.3.1 Saw Type

Saw Type does not effect the finishing state on the general defect evaluation, but the analytical result of main effect on Saw Type relating to third level "hang-nail", in which the score in the case of "hang-nail" occurrence is 1 and the score in the case of no "hang-nail" occurrence is 0, presents the significance at 1% level of F-test (Fig. 5). From this result in Fig. 5, "filed saw" sometimes occurs "hang-nail" defect in the finishing state, but "tipped saw" rarely does. We need to pay attention to this result to improve the saw type in the future.

4.3.2 Main effect of Size of Twig (Fig. 6.1, significance at 1% level, ρ: 3.79%)

The finishing state on "small" Size of Twig is about twice worse in comparison with "large" one. The smaller the twig, the more attention has to be paid.

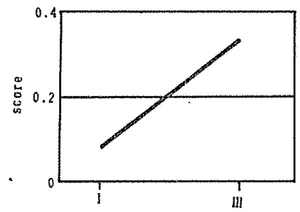

Fig. 5 Finishing state "hang-nail" evaluation on Saw Type
Ⅰ: tipped saw
Ⅲ: filed saw

4.3.3 Main effect of Cutting Speed (Fig. 6.2, significance at 1% level, ρ: 33.46%)

Cutting Speed "fast" occurs often pretty bad defects in the finishing state, which score 5 is very high. Therefore, the finishing state contains sometimes "split". As Cutting Speed is the most important factor on the finishing state, it needs to be kept on Cutting Speed "slow" not only for good finishing state, but also for

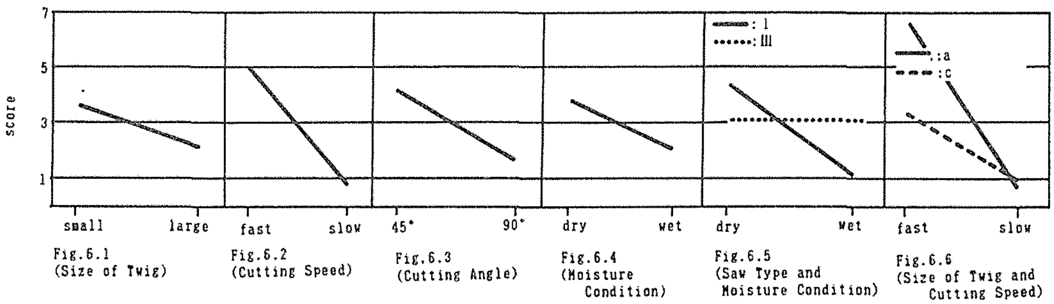

Fig. 6 Finishing state: general evaluation
Ⅰ: tipped saw a: small
Ⅲ: filed saw c: large

comparatively moderate impact to the pruning trees.

4.3.4 Main effect of Cutting Angle (Fig. 6.3, significance at 1% level, ρ: 11.65%)

The finishing state on Cutting Angle 90° is pretty well and contains only a little worse defect than on "rough" finishing level. On the other hand, the case on Cutting Angle 45° is worse than on "hang-nail" level. From this result, it has to be cut perpendicularly to the longitudinal direction of twigs.

4.3.5 Main effect of Moisture Condition (Fig. 6.4, significance at 1% level, ρ: 4.83 %)

Moisture Condition "dry" occurs a little worse than "hang-nail" defect in the finishing state. This result means that an operator usually has to prune in dry winter season in which it is unsuitable for the finishing state of cutting surface.

4.3.6 Interaction between Saw Type and Moisture Condition (Fig. 6.5, significance at 1 % level, ρ: 4.30%)

The finishing state on "filed saw" is unchangeable whether "dry" or "wet" condition, but the case on "tipped saw" sometimes contains "split" defect, because this case score 4.3 is higher than "hang-nail" score 3. (note: we mentioned the effect of only one finishing state category "hang-nail" information in 4.3.1, but in this section, we treated with the general evaluation information.)

4.3.7 Interaction between Size of Twig and Cutting Speed (Fig. 6.6, significance at 1% level, ρ: 5.39%)

The finishing state on factorial combination of Cutting Speed "fast" and Size of Twig "small" is especially bad. This factorial combination occurs very often a "split" defect in the finishing state.

As we discussed the factorial effects about the finishing state above, we need to cut twigs at "slow" Cutting Speed and on Cutting Angle 90° to the longitudinal direction of twigs. As pruning operation is popularly performed in dry winter season, we have to pay extra attention to pruning small twigs, which are apt to split under dry condition.

5. Afterward

In this paper, we discussed mainly the analytical results of experimental designs of orthogonal array L_{27} (3^{13}), exclusive of the finishing state category "hang-nail" informatio n in 4.3.1 according to the result of experimental designs of orthogonal array L_{16} (2^{15}). We intend to present the analytical results about the finishing state category "split", "rough" and "smooth" in another paper.

We want to make a saw type composed of new teeth which the cutting surface state would be finished as smoothly as with hatchets.

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