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Studies on the Cultivating Characteristics of the Knife Edge Curve of Rotary Blade (Part II)

Effects of Edge Curve on Soil Cutting Resistance

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The edge curve angle of a vertical rotary blade has a considerable influence on the cultivating resistance, the reactions or penetrating actions of the soil, and the entwining phenomenon of grass or straw. In this paper, the experimental results of the effects of the edge curve on the maximum cultivating torque and the cultivating work were reported with regard to the cases of the fixed rotation (circle) and the traveling rotation (trocoid curve). The theoretical operational rotating angle θ_{op} which has been already obtained in the previous report were used for the calculation of the cultivating work W. The minimum values of the maximum cultivating torque and work were reached at an edge curve angle of 55" to 60' under all conditions. Since it is generally recognized that this value of the edge curve angle is in the permission limit of the entwining phenomenon of grass or straw, it may be considered that this range of edge curve angle of a rotary blade is the most reasonable one.

INTRODUCTION

The shape of the knife edge curve of a rotary blade produces a significant effect on the soil cutting resistance and the entwining phenomenon of grass or straw on it. Therefore, the decrease of the cutting resistance and the control of entwining are important subjects in the design of a rotary blade which has better cultivating characteristics.

The characteristics of a soil cutting resistance were already made clear experimentally on the edge cutting angle γ between a tangential line of the edge curve and a tangential line of a locus curve at a certain point, as one of the working angle elements, and the entwining of grass or straw was theoretically considered (Matsuo, 1961). The later studies in regard to the edge curve angle α between the radius direction and a tangential line of the edge curve, as one of the shape angle elements, indicated that the entwining phenomenon scarcely occured when a value of the edge curveangle was larger than 57. 5" (Taguchi, 1962) or when this value was 55" on the tip portion and 65" on the neck (holding) portion of a blade (Sakai et *al.*, 1976). But the quantitative characteristics of soil cutting resistance were not thoroughly investigated in these reports. Therefore, the effect of the edge curve angle of a rotary vertical blade on the cutting resistance was synthetically investigated in this paper.

MATERIALS AND METHODS

Experimental apparatus

The outline of the experimental apparatus of this study is shown in Fig. 1. A rotary shaft (3) with a blade (4) is driven by an electric motor (1) through a chain tension adjuster (2) and the blade is fixed on a holder (5) which can move in the direction of the shaft, and inside of the rectangular rigid frame (6) that can be vertically moved. The cross gauges were placed at the point (A) on the surface of a rotary shaft (3) to determine the cultivating torque. The soil bin (10) with 60cm width, 50 cm height and 300 cm length can be moved on two rails (11) with variable speed in a forward or a backward direction by an electric motor (7) through a stepless speed change device (8) and a chain (9). The rotating speed and the rotating position of shaft were determined electrically by the marks on a recording oscillograph due to the four projections on the shaft.

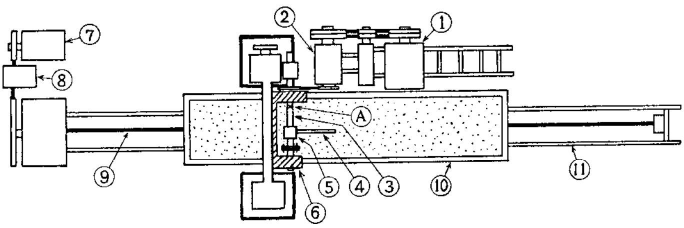

Fig. **1.** The schematic plane view of experimental apparatus.

Soil condition

The results of the size analysis of the tested soil by the hydrometer method (JIS. A. 1204) is shown in Fig. 2 and Table 1. This soil was placed uniformly in the soil bin with about 10 cm height and was compacted by foot, this work was repeated up to 45cm height of soil.

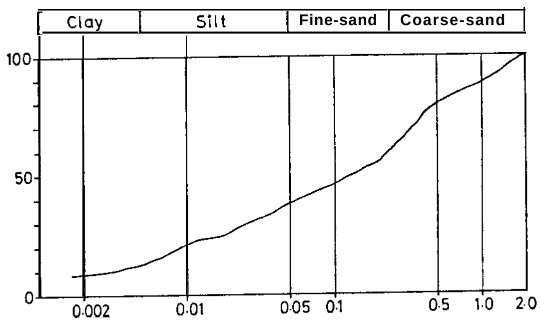

Fig. *2.* Grain size accumulation curve of tested soil.

Table 1. The physical properties of the tested soil.

Classification	Silty loam (black, volcanic)
Specific weight	2.55
Liquid limit	58.75
Plasticity limit	45.90
Plasticity index	12.85
Liquid index	22.50

The soil hardness values obtained by Yamanaka's soil hardness tester were about 8-9 kg/cm² and the moisture ratios were 34~52% for the tested soil.

Shape of tested blade

The knife edge curve with a constant edge curve angle α was usually shown as a logarithmic spiral line (Takahashi *et al.,* 1971). Therefore, since there are two limits of the blade width ***b*** at the blade holder and the radius h_n of a chain case of gear box of a shaft, the edge curve equation will be able to be written as follows :

$$r = \left[(h_n)^2+\left(\frac{b}{2}\right)^2\right]^{\frac{1}{2}} \cdot e^{\theta \cot \alpha} \qquad (1)$$

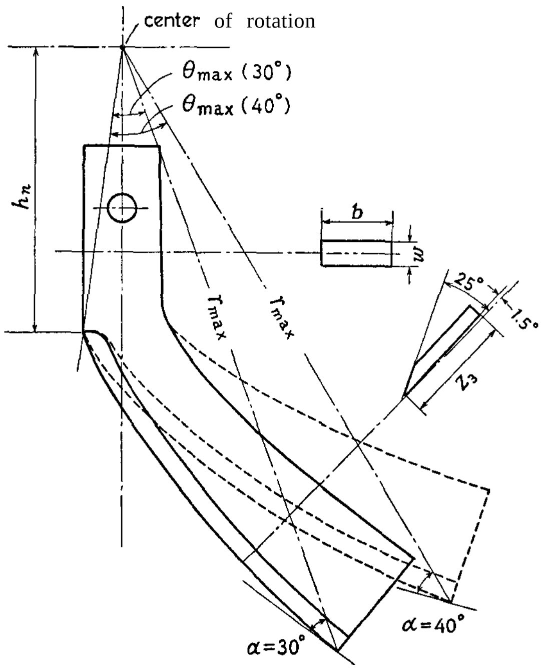

Fig. 3. Experimental rotary vertical blades with edge curve angle of 30" and 40".

where

- ***r*** **:** Distance from the center of shaft to a optional point on the edge curve (the maximum value $R=200$ mm).
- ***b*** **:** Blade width at the blade holder, in this study $b=24$ mm
- h_n: Radius of a chain case or a gear box, in this experiment $h_n=80$ mm.
- e **:** Inclusive angle of the edge curve from the neck (holding) portion to a optional point on the edge curve in degree.
- α : Edge curve angle which was changed 30°, 40°, 50°, 60" and 70" in this study.

The edge curve were obtained as shown in Fig. 3 in the first report (Matsuo and Hai, 1978) when the above conditions were put in the equation (1). In the cases of angle α of 30" and 40°, the widths at the tip of each blade are 40 mm and they decrease to 24mm toward the holder as shown in Fig. 3. The one sided sharping blade was used in consideration of the reduction of the cutting resistance. (The comparison of the one sided sharping blade and two sided one will be reported in the after report).

Experimental conditions

In actual cultivation, the blades are disposed on the shaft at intervals of 3cm to 6 cm, by the time it penetrates through the soil. To approximate this experimental condition to an actual condition, the blade was removed beforehand with some intervals L_b as shown in Fig. 4. The smaller the length of interval L_b the greater the reduction of the soil reaction from the removed soil.

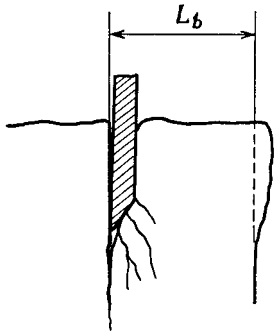

Fig. 4. The cutting section of soil with the cutting width L_b.

There are several methods to express the soil cutting resistance on the blade under both fixed rotation and traveling rotation.

Those are the maximum torque T_{max}, the mean torque T_{mean} and the corresponding work ***W*** which is indicated as the area ***T-O*** (kg•m•deg or kg•m•rad) surrounding the torque curve and the rotation angle axis. The corresponding work method is the most desirable expressing method (Matsuo, **1961).**

In this study, the maximum torque and the work were used for the comparison of the cutting resistance with the change of the edge curve angle α from 30° to 70°. Since the edge curve angles are different one another, the operational rotating angle θ_{op} which is the rotating angle between from the beginning to end of the soil cutting have to be obtained, those were already shown in the previous report (Matsuo and Hai, 1978). In this experiment, the measured operational rotating angles θ'_{op} are larger than the theoretical angles θ_{op}, because of the limit of motor torque and the slip of driving belt, etc. However, the mean cultivating torque T_{mean} is obtained from the measured operational rotating angle θ'_{op} and the work W is calculated from the following equation

$$W = T_{mean} \cdot \theta_{op} \tag{2}$$

where

T_{mean} : Mean cultivating torque (kg・m).
θ_{op} : Operational rotating angle (degree).

RESULTS AND DISCUSSION

The effects on the measured maximum torque T_{max} and the cultivating work W with the change of the edge curve angle α during a rotation of the blade are shown in Fig. 5-7. The maximum torque and the cultivating work are increased with the increase of the edge curve angle when the cutting width L_b is much longer, but have a minimum value at the range of the edge curve angle α of 55° to 60° when the cutting widths L_b are 4 cm and 6 cm. For these reasons, it was considered that the friction forces grew in response to the normal forces between soil and both sides of a blade, according to the penetration of the blade into the soil and the scratching length on both blade surfaces. In other words, these friction areas increased with the increase of the edge curve angle in the case of a very long cutting width (approximate to $L_b = \infty$). In case of the actual cultivating, however, this cutting width is about 3 cm~6 cm due to the distribution of the blades on a rotating shaft (rotary axle). The soil is divided and is only pushed away, and is broken

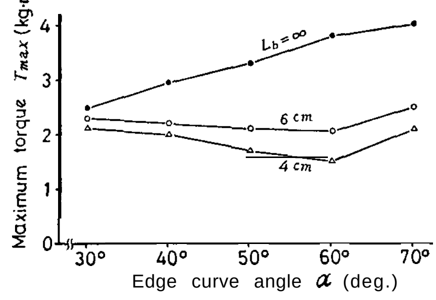

Fig. 5. The effects of cutting width L_b and edge curve angle on the maximum torque, where revolution of shaft $n = 200$ rpm, ground speed $v = 3.34$ cm/s, pitch $P \doteqdot 1.5$ cm, maximum radius $R = 22$ cm and depth $H = 10$ cm.

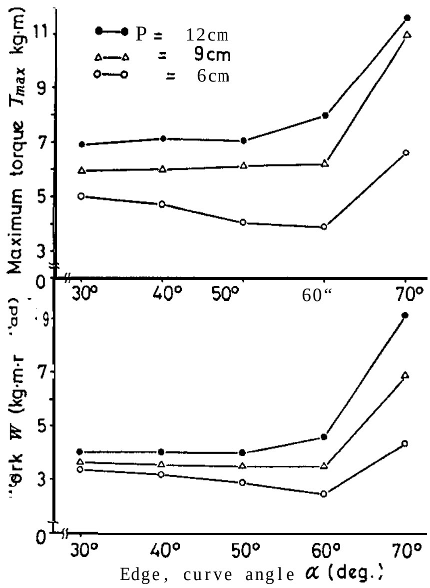

Fig. 6. The effects of edge curve angle on the maximum torque and the cultivating work in the case of fixed rotation, where cutting width $L_b=3$ cm, maximum radius of blade $R=22$ cm and depth $H=12$ cm.

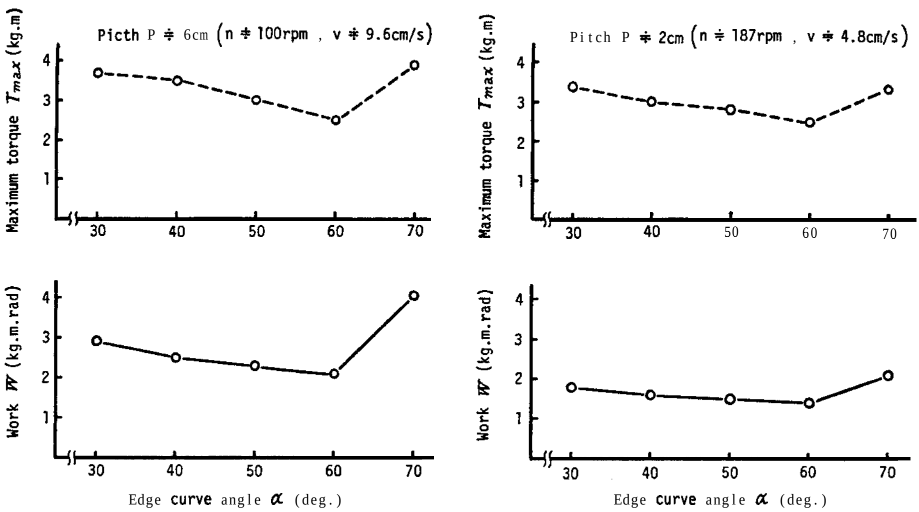

Fig. 7. The effects of edge curve angle on the maximum torque and the cultivating work, where cutting width $L_b=3$ cm, maximum radius $R=22$ cm and depth $H=12$ cm.

easily with little frictional resistance by a penetrated blade (soil of right side in Fig. 4). Therefore, when the cutting width is 4cm or 6 cm as shown in Fig. 5, the values of cultivating maximum torque were considerably smaller than the previous case, and decreased gradually with the increase of the edge curve angle from 30" to 60°, but increased suddenly when the angle α is larger than 60". These phenomena can be explained by three effective causes to the cultivating resistance as follows : First, the characteristics of the edge cutting angle such as that of the former report (Matsuo, 1961) which showed the differences in the soil breaking mechanism due to changes of the edge cutting angle γ. Second, the decrease of soil cutting resistance by the decrease of the sharpening (lip) angle with the increase of the edge curve angle α. Third, the increase of the soil cutting resistance with the increase of the scratching length or the frictional area. Since the edge curve becomes very long when the edge curve angle is over about 60°, the last cause effects mainly the soil cutting resistance.

In order to substantiate these phenomena, the various experiments were performed changing the cultivating conditions and factors. These experimental results were indicated in Fig. 6 and 7 for the change of cultivating pitches in each case of the fixed rotation and the traveling rotation, respectively. According to the former reports (Taguchi, 1962 and Sakai *et al.*, 1976), a desirable value of the edge curve angle in regard to the entwining phenomenon of grass or straw almost coincide with that of the soil cutting resistance. In other words, the range of the edge curve angle of 55" to 60" will be the most desirable for both characteristics of soil cutting resistance and grass entwining, and the equation of the desirable edge curve of a blade may will be obtained by use of these results.

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