Designing Process and Theories of Rotary Blades for Better Rotary Tillage (Part 2)

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As the present paper is the continuation of the Part 1, which was published in the preceding issue of this journal, numberings of figures, tables and equations follow those of Part 1.

Determination of tip-end of edge-curve

The length L_0 necessary for the imaginary unbent shape of the sidelong blade was obtained at the stage (e) of Fig. 3. The distance ε between both tip-ends of the actual sidelong blade and its imaginary shape before bending will be decided using L_0. The distance is used to decide the relative location of A_0, at the lowest point of backside curvature of the tip-side of the scoop-surface, to the edge-curve as shown in (g) of Fig. 7.

Namely, the line $\overline{A_0F}$ crossing the line of radius direction by an angle ϕ shows the moving direction of E to the point A_0, when the scoop-surface is formed by a press machine. This means that the location of A_0 to E, the intersecting point of the extension line of $\overline{A_0F}$ to the edge-curve, must be selected so as to be $EA_0=\varepsilon$ on the tip circle of the blade. The point E shows the location of the tip-end of the edge-curve before bending. The location dimension of L_2 and l_1 for E, and L_1 and l_2 for A_0 will be obtained after completing the drawing shown in (g) of Fig. 7.

Planning of vertical end shape and cross section of scoop-surface

Without rational design theories the scoop-surface sometimes shows a simple and flat surface as given in Fig. 8. Considering the angle β_1 between such a flat scoop-surface and lines of radius direction, the angle β'_1 at the upper part of the scoop-surface may have the following relation with the angle β''_1 at the lower part of the same scoop-surface:

$$\beta'_1>\beta''_1 \text{ and } \beta'_1=\beta''_1+\sigma \quad \cdots\cdots (9)$$

It expresses that the lower part of the surface has stronger throwing effects to soil clods than the upper part of the surface.[3]

It is also thinkable that the upper portion of scoop-surface has no throwing-back effect to soil clods when the angle β'_1 becomes greater than or equal to the calculated value β of equation (6). This provides that the rational design for the angle β_1 should meet the condition of:

$$\beta'_1\leqq\beta''_1 \quad \cdots\cdots (10)$$

and that the vertical section of scoop-surface has to take a certain curved-form as shown in Fig. 9. Design theories for the scoop-angle β_1 of scoop-surface are formulated so as to give some reasonable soil-throwing performance thought by designers.[10]

The author names the edge portion of scoop-surface as "first scoop-surface" and the other upper portion as "second scoop-surface"[4][10] (Fig. 9.). According to the observation, soil slices of medium soil of paddyfields cannot be thrown by one cutting pass of the blade which was designed using β_1 of the whole scoop-surface nearly equal to the angle β calculated from equation (6).[3] This phenomenon shows that the first scoop-surface has a small contribution to the throwing ef-

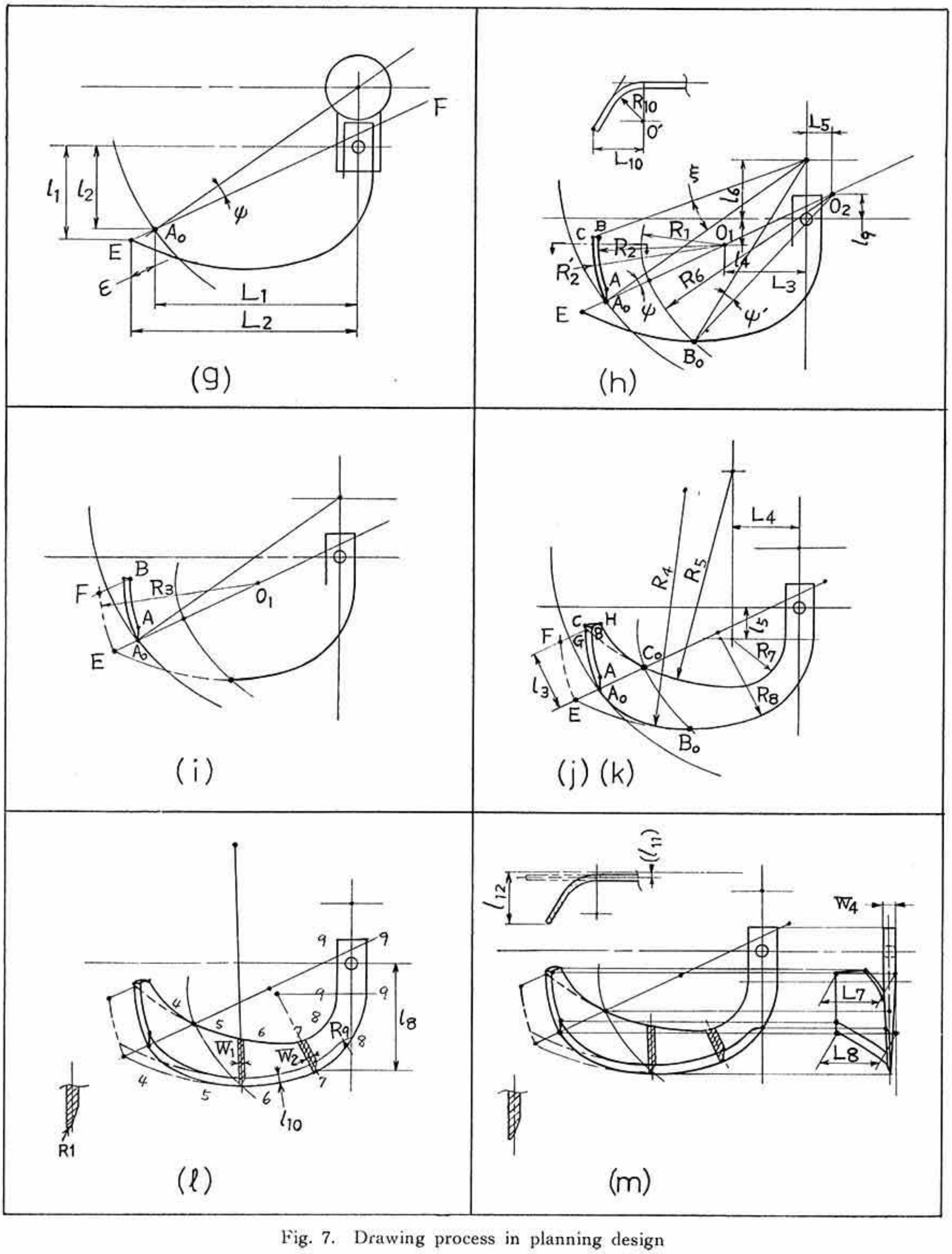

Fig. 7. Drawing process in planning design

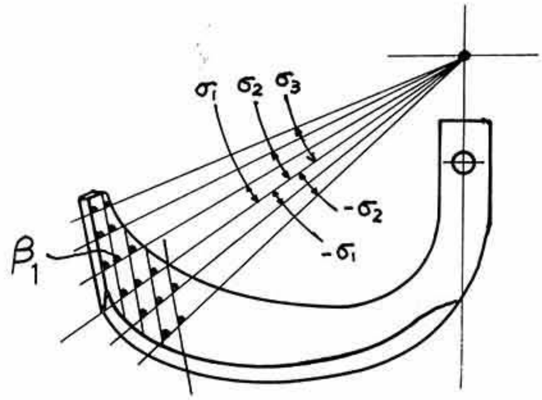

Fig. 8. Poor scoop angle β_1

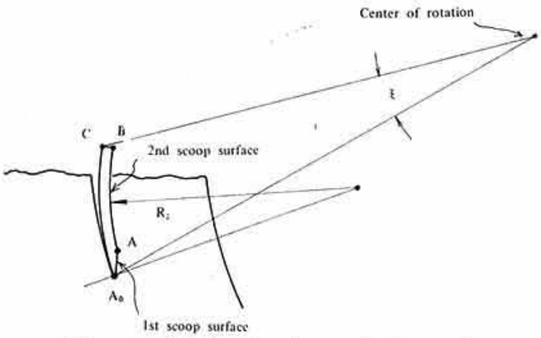

Fig. 9. Relative location and shape of scoop-surface

fect, so that the proper throwing effect should be given mainly by the second scoop-surface.

Although the strict design process and theories of the second scoop-surface $\widehat{AB}$ were studied,[10] on the basis of these ideas and also the shape of the first scoop-surface $\overline{A_0A}$ in Fig. 9, an idea of almost uniform thickness of the vertical cross section of the second scoop-surface was also found useful for formulating a rational design theory from the viewpoint of practicality and simplicity.[10]

The practical method is to obtain at first the backside curvature $\widehat{A_0C}$ with reasonable soil-throwing effect, and then to draw the line of the edge shape $\overline{A_0A}$ and the second scoop-surface $\widehat{AB}$ along the inside of the curvature $\widehat{A_0C}$. The practical process of designing the scoop-surface is expressed in Fig. 10. At the first stage (h_1) of the process, values of the following design factors must be carefully selected.

R : blade turning radius, cm
H : maximum depth of tillage, cm
n : rpm of rotary axle
υ : travel speed of the machine, cm/sec
ξ : angle of the vertical section of the whole scoop-surface to the center of rotation (Fig. 9), degree
l : horizontal throwing distance of the soil slice, cm

The values of n and υ are selected so as to make the value of β small within the limits of soil conditions to be considered. A bigger value of υ and a smaller value of n are employed to calculate a smaller value of β.[3,4] (These values were previously used to check β and to decide β_1 at the stage (f) of Fig. 3. At this stage, appropriate values of n and υ have to be confirmed with the idea of escape angle γ.)

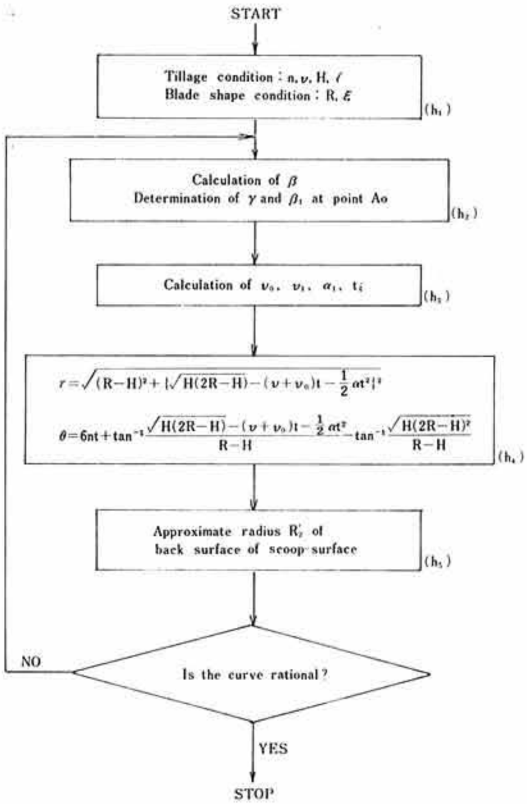

Fig. 10. A flow chart of planning design for scoop-surface vertical section

The angle of the scoop-surface to the center of rotation is also checked and confirmed by considering the blade life demanded by farmers. Its usual value is 10 to 15° for Japanese small scale farming.

The value l is the necessary moving distance of the soil clod never to be beaten by the blade of the second rotation. The value of l is calculated from the minimum value l_{min} as shown in Fig. 11 and some allowance is added as follows[10]:

$$l_{min}=\sqrt{H(2R-H)}+\frac{30}{\pi\lambda}\left\{\pi-\cos^{-1}\left(1-\frac{H}{R}\right)\right\} \quad\cdots\cdots(11)$$

$$l=l_{min}+(0 \text{ to } 10\text{ cm}) \quad\cdots\cdots(12)$$

where

$$\lambda=\frac{n}{v} \quad\cdots\cdots(13)$$

After calculating l, the following values will be calculated at the stage (h_3) of Fig. 10:

v_A : tangential rotation speed of the bottom point A_0 at the soil surface at tilling depth H, cm/sec

v_0 : horizontal backward primary-speed of the soil at the soil surface at tilling depth H, cm/sec

v_1 : necessary horizontal speed of the soil to fly the distance l, cm/sec

α : necessary acceleration speed, cm/sec²

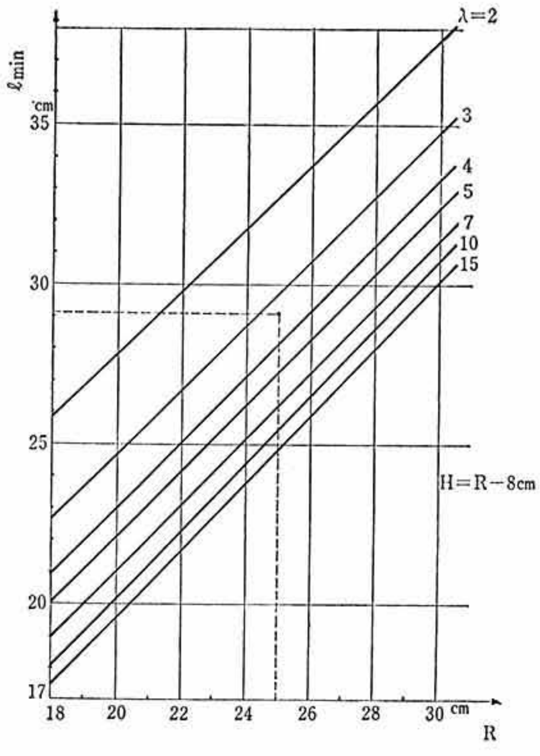

Fig. 11. Minimum necessary distance of throwing soil clods (l_{min}) for H=R− 8 cm[10]

$$v_A=\sqrt{\frac{(Rn\pi)^2}{900}+v^2-\frac{n\pi v(R-H)}{15}} \quad\cdots\cdots(14)$$

$$v_0=v_A \sin\gamma \quad\cdots\cdots(15)$$

$$v_1=l\sqrt{\frac{g}{2H}} \quad \text{where } g=980\text{ cm/sec}^2 \quad\cdots\cdots(16)$$

$$\alpha=\frac{6n(v_1-v_0)}{\xi} \quad\cdots\cdots(17)$$

t_1 : parameter to calculate r and θ of polar equations, sec

$$t_i=\frac{\xi}{6n} \quad\cdots\cdots(18)$$

The parameter t_1 is the total passing time of the curve $\widehat{A_0C}$ against the soil surface. The value of t_1 will be divided into five to ten and substituted into the following polar equations, as the step (h_4) of Fig. 10:

$$r=\sqrt{(R-H)^2+\left\{\sqrt{H(2R-H)}-(v+v_0)t-\frac{1}{2}\alpha t^2\right\}^2} \quad\cdots\cdots(19)$$

$$\theta=6nt+\tan^{-1}\frac{\sqrt{H(2R-H)}-(v+v_0)t-\frac{1}{2}\alpha t^2}{R-H}-\tan^{-1}\frac{\sqrt{H(2R-H)}}{R-H} \quad\cdots\cdots(20)$$

Fig. 12 shows an example of $\widehat{A_0C}$ curvature obtained from equations (19) and (20). The radius R'_2 as shown in Fig. 12, which expresses the curvature in a simple arc $\widehat{A_0C}$, has

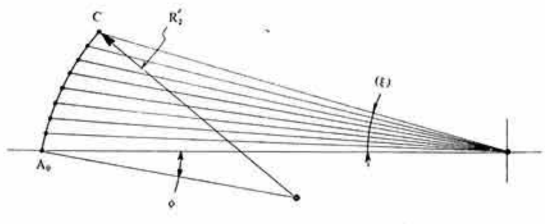

Fig. 12. Calculation of scoop-surface and planning design

to be estimated at the step (h_5) of Fig. 10. When these results are all reasonably correct, the dimensions l_4 and L_3 to express the location of the center O_1 of the radius R'_2 will be determined as shown in (h) of Fig. 7.

The arc $\widehat{AB}$, expressing the scoop-surface, is drawn by the radius R_2 with the idea of the tip thickness W_3. The thickness W_3 of the blade tip and knife-edge width l_{10} are decided tentatively depending on strength, life and production method of the blade. These values

Table 1. Actual values of W_3 and l_{10}

PS	5 to 15	15 to 25	25
W_3	3.5 to 4	4 to 6	> 6
l_{10}	6 to 9	8 to 14	>10

(mm)

under Japanese farming condition in general are shown in Table 1. ((l) of Fig. 7)

The knife-edge at the scoop-surface is recommended to be the shape of a single edge. The edge angle (lip angle) ε_1 at the blade tip will be tentatively decided and drawn at this step, and the final value of ε_1 will be decided when the sectional shape of the whole blade is decided at the step (l) of Fig. 7.

Next, the passing line of the radius R_{10}, decided in the (e) of Fig. 3, has to be formed. There are several different methods to express the form of the scoop-surface according to designers. The author recommends the design principle that it is natural and reasonable for the function of tip blade to make the lower part of the scoop-surface cut into the soil with smaller resistance possible, expecting the upper part of the scoop-surface to give rational throwing back and reversing actions to the soil slice.[3,4,10] The (h) of Fig. 7 is one of design methods of expressing this idea. Namely, the distance between the center O_1 and the blade tip, L_{10}, will be obtained in the first step. Then, the radius R_1 is calculated from the following equation:

$$R_1=(R'_2-L_{10}) \quad \cdots\cdots\cdots\cdots (21)$$

The arc of R_1 only above the line $\overline{EO_1}$ will be drafted. This arc of R_1 should continue to another arc of the radius R_6, centering in O_2 that locates on the extension line of $\overline{EO_1}$.

The centering location of O_2 is decided so as to be ($\psi' \doteqdot \psi$) as shown in (h) of Fig. 7. The location distance l_9 and L_5 are obtained by this way.

Shape of the blade tip before bending

It gives information of material pre-shaping before the pressing process finalizes the shape of scoop-surface. The direction of press differs very delicately depending upon the manufacturing methods, so that the actual shape of unbent blade has to be adjusted by manufacturer using the dimensions of the unbent view in the drawing.

The base line $\overline{O_1E}$ in (h) of Fig. 7 expresses approximately one of the bending directions of the material when the scoop-surface is shaped in the pressing process. Therefore, as shown in (i) of Fig. 7, the arc of the radius R_3, centering at O_1, is to be drafted. The parallel line from the point B to the pressing direction $\overline{O_1E}$ will cross the arc of R_3 at F. The curve $\widehat{EF}$ shows the imaginary tip shape before bending.

Back curve of the whole blade and the whole shape of the blade before bending

The back curve of the blade should be given the proper shape with a wear-resistant character. As a single arc is difficult to cover the whole back curve, two arcs of R_7 and R_5, (j) (k) of Fig. 7, are usually used to express it.

The location distance l_5 and L_4 of each radius center are obtained. The center of R_7 locates on the horizontal line of the center point of the radius R_8, while the center point of R_5 is on the vertical line of that of R_7. The arc of the radius R_4 has to express approximately the spiral curve $\widehat{EB_0}$ and to connect with the arc of R_8.

The imaginary shape of $\widehat{BH}$ and $\widehat{CH}$ at the blade tip, which is determined by the dimension of l_3, will be drafted. In some cases, the locations of these C and H points are expressed in the dimensions of the product for the convinience of the product inspection process. $\overline{FG}$ may not always be a straight line, but is sometimes an arc.

At the last stage of this design process, the edge-curve $\widehat{A_0B_0}$ and the back curve $\widehat{HC_0}$ that are imaginary curves are to be drawn.

Shape of cross section including knife-edge

Japanese-type rotary blade has, as a rule, a gradual change in blade thickness from a thick shank portion to a thin tip portion. This tendency has to be expressed by two to three sectional shapes of the blade.

Thickness distribution will be tentatively written along the edge curve and back curve ((*l*) of Fig. 7) and checked at the stage of planning design. It is easy and natural to manufacture the blade with the back portion a little thicker than the edge portion, somewhat like a wedge-type. However, from the viewpoint of relief (escape) angle between the side surface of blade and its cutting soil, the wedge-type is not always rational and the section of equal thickness is more rational to have a smaller cutting resistance.[4)11)12)]

The thickness W_1 and W_2 and their locations are decided with these design know-hows including the whole cross sections. Accordingly, some designers give individual dimensions of W_{1a} and W_{1b} to the back portion and edge portion with dimensional allowances. The allowance is the forging allowance of less than 1 mm. The allocation of plus and minus values of the allowance reflects each designer's idea about tillage performance and/or production method of rotary blade (for example, ± 0.5, ${}^{+0.7}_{-0.3}$, ${}^{+1.0}_{-0}$, ${}^{+0.3}_{-0.7}$, ${}^{+0}_{-1.0}$, etc.)

There are two kinds of edge shape, single edge and double edge.[4)] European blades are usually single-edged and Japanese ones double-edged. When hard soil has to be tilled, the single-edged blade reduces the tillage resistance in comparison with a double-edged one by 20 or more %.[11)12)] Too small a sharpening angle on the edge deforms the knife-edge in the production process.[4)]

When the width l_{10} of the knife-edge is determined, the edge line is drafted as shown in (*l*) of Fig. 7. The dimension R_9 expressing the shape and location of the edge end has to be determined. Special cross section is sometimes written in order to show accurate shape as shown in (*l*) of Fig. 7.

Side view

The side view of the blade is drawn in order to express the whole body that cannot be shown by only the shape of a horizontal section of the scoop-surface written at the left upper corner of the design sheet. Cutting width of the sidelong blade is determined by the upper width L_7 and lower width L_8. In general, L_7 is equal to or a little smaller than L_8.

Drafting after the planning design

When a planning design is completed for a new blade, the blade with necessary dimensions like Fig. 1 has to be drawn on a new tracing paper with remarks for manufacturing it. Necessary items of remarks are as follows:

Material

In general, spring steel is commonly used. SUP-6 of Japan Industrial Standards (JIS) is the most standard one in Japan.[4)]

Heat treatment

Hardness after heat treatment has to be indicated. H_RC 50±3 to the whole blade was usual formerly, but after about 1965, advanced heat treatment to give H_RC 50 to 55 from the center to the tip portion and H_RC 40 to 45 to the shank portion became popular in Japan, making it possible to give a longer life to the blade and bigger strength to the shank.

Marking

The name or mark of brand, part number or type number including the indication of left or right blades according to the direction of the sidelong blade, etc. has to be marked. The size and location of the marks are carefully decided to avoid breaking or bending troubles of the blade. The depth of marking press may be 0.2 to 0.3 mm in general.

Surface finishing

The blade must have a rustproof finishing laquer applied on it. The color and sort of painting have to be explained.

Days for finishing planning design and drawing a new rotary blade

It may take about one week to complete a planning design for a new rotary blade, and one or two days to draft a production drawing after the planning design.

Summary

The latter half of the planning design process for Japanese-type rotary blade is discussed, based on results of research on individual design elements. Drawings at each stage are shown in Fig. 7. The design of the scoop-surface is critically important for the blade to perform effective cutting, throwing and mixing of soil. The practical process derived from theoretical research on the scoop-surface is explained, with a flow chart of Fig. 10. The design of straight (lengthwise) blade is also important in terms of its influence upon cutting resistance.

After finishing the planning design, the drawing of the production model has to be done with indicated dimensions for production purpose, and also the notice for material, heat treatment including hardness, marking, surface finishing, part and type number, etc.

References

(Refer to Part 1 for reference number 1 to 10)

11) Sakai, J. et al. : Design theories of rotary blades for tractors (Part 4), Practical concepts of single and double edge blades, Summary of JSAM 36th Annual Convention, No. 1-24, (1977)

12) Sakai, J. : Studies on design theories of single-edged and double-edged rotary blades for tractors. I. *Bull. Facul. Agr. Mie Univ.*, No. 58 (1978) [In Press].