IRON WHEELS FOR PLOWING WITH WALK-BEHIND TILLER

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ABSTRACT

The relationship between the plow, the walk-behind tiller and the iron wheels were expressed mathematically in the standard plowing forms of the whole machines. The analysis and design theories of the plowing wheels were derived dy discussing these relationships in the previous paper [1].

In this study, the rational structure and shape of plowing wheels particular wheel lugs are designed based on those design theories. Furthermore, a prototype of iron wheel is fabricated and operating tests are conducted in paddy fields. It is found that the whole machines perform high working stability with free-hand plowing.

KEYWORDS

Forward lug, outside lug width, inside lug width, groove curve, installing angle of forward lug

INTRODUCTION

Many kinds of iron wheels for walk-behind tillers are widely used in lowland-paddy farming operations such as plowing, puddling and so on in Asian countries. Those wheels are designed to obtain higher performance in specific conditions of muddy field than pneumatic tires. However, unsuitable iron wheels may cause low working efficiency to the tiller as wsll as difficult working conditions for operators. This is due to agricultural machines are area-oriented machines. Therefore, a reasonable structure and shape of iron wheels are needed for each field operation and conditions.

Several studies on the acting forces on iron wheels without attachments have been conducted. Cheu-Shang Chang [2] tested six commercial rigid lugged wheels operating in a saturated clay soil with hardpan 150 mm below the soil surface and found that the calculated torque arm from the accurate solution is equal to or less than the measured radius. David Gee-Clough [3] measured soil-lug forces and reported that the 35° lug developed larger lift and pull forces but lower levels of pull per unit width than did the 0° lug. Lal S. Wimalawansa [4] tested cage wheels for a medium powered tractor and reported that a lug spacing of 24 degrees with lug angle of 30 degrees was the best of cage wheels with lug height of 100 mm and diameter 1415 mm.

In this study, prototype of iron wheels for

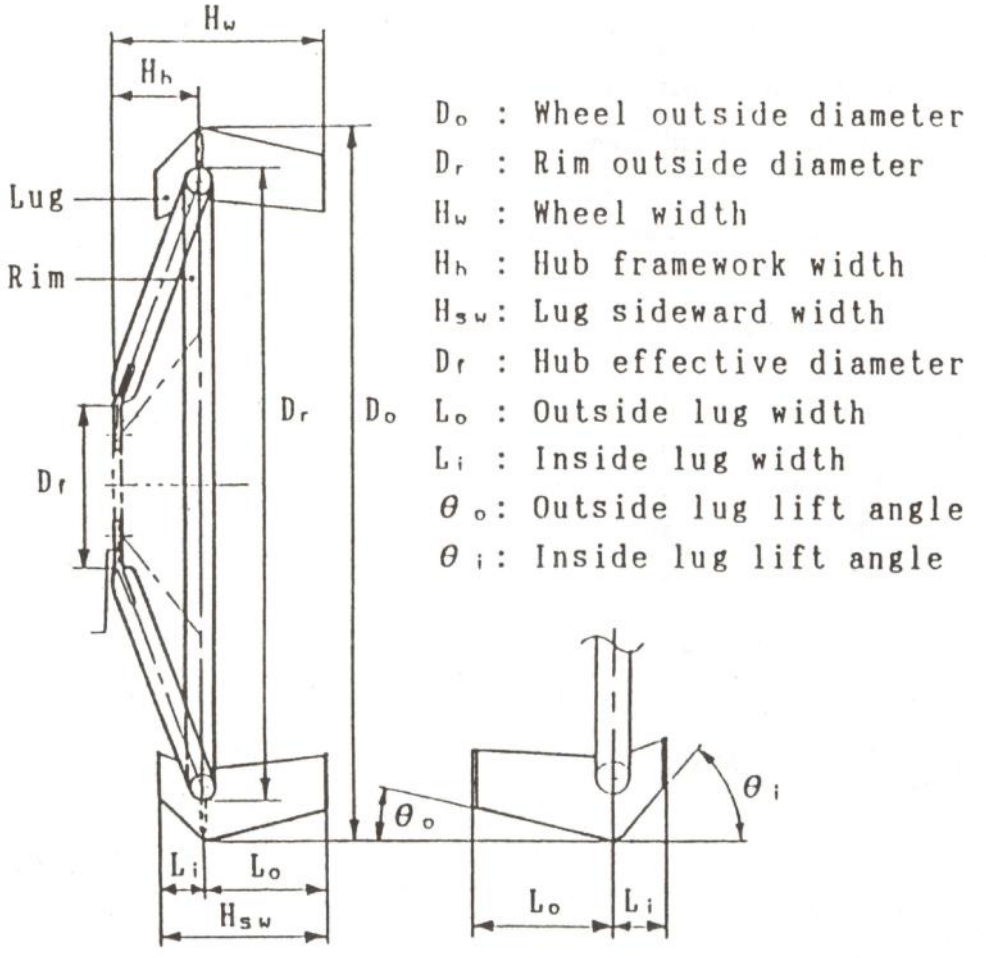

Figure 1 Terminology for plowing wheel

plowing are designed according to design theories based on the standard plowing. An optimum wheel structure and special shape of lug for stability plowing is primarily desired.

TERMINOLOGY FOR PLOWING-WHEELS

Terminology for the plowing iron wheels has not been approved in academic societies though the terminology for tractor rubber tires has already been done in the ASAE Standard [5]. Some important parts' names and dimensions of the plowing wheels are proposed as the terminology as shown in Fig.1 though their essential components are similar to cage wheels and other iron wheels.

DESIGNING OF WHEEL LUGS

In the best and standard plowing, plowing wheels are required to have good tractive performance. Forward lugs which can produce net traction with small motion resistance may be designed with better understanding of the relationships between the tiller, the plow and the wheels. Therefore, the shape of a forward lug has to be decided so as to come in contact with furrow bottom and furrow wall for stability plowing and high tractive ability

Detail Designing of Lug Plate

Forward lugs are manufactured of steel plate bars or sheets for general structure. Firstly, a flat bar is cut into pieces and formed into the designed dimensions as shown in Fig.2 by a gas cutting device or a press machine. Secondly, a groove for installing the plates on a rim is cut accurately. Curves of the groove can be approximated to ellipses. Finally, the plates are bent to a specified angle with red hot heating by gas device and hitting. Figure 3 shows the dimension of a lug plate before and after bending. Though the plate thickness around groove may sometimes become thin by heating and bending, this is neglected in this paper for the basic design equation.

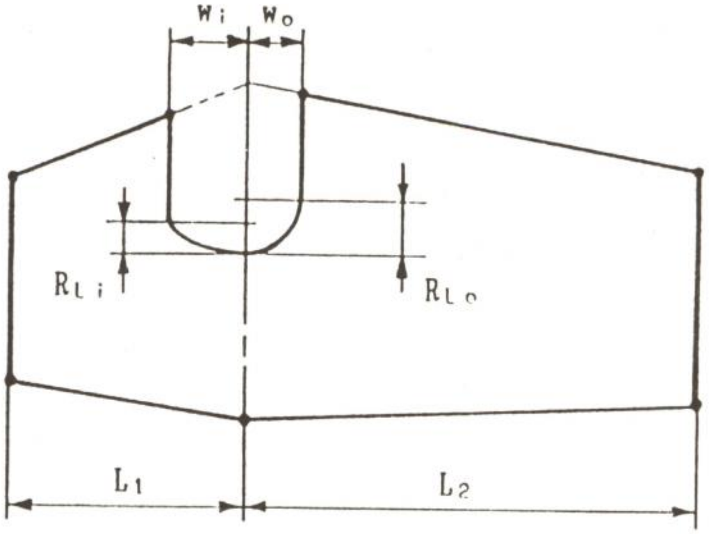

Figure 2 Dimensions of lug plate

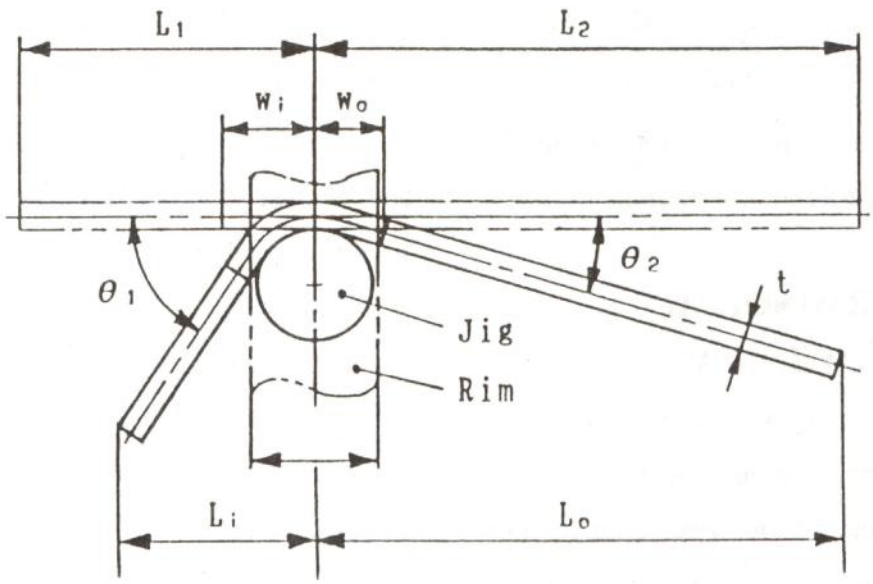

Figure 3 Lug plate before and after bending

Lug plate Length

The outside lug width L_o and the inside lug width L_i are decided in the previons paper [1] as planning design. In order to fullfill these width, inside plale length L_1 and outside one L_2 can be calculated from bending angles θ_1 and θ_2 , plate thickness and jig radius r_j from geometrical analyses.

From Fig. 3, L_i and L_o can be expressed as follows :

$$L_i= \{L_1 - (r_j + \frac{t}{2}) \theta_1 \}\cos \theta_1 + (r_j+t)\sin \theta_1 \quad (1)$$

$$L_o= \{L_2 - (r_j + \frac{t}{2}) \theta_2 \}\cos \theta_2 + (r_j+t)\sin \theta_2 \quad (2)$$

Rearranging Eqs. (1) and (2), and solving for L_1 and L_2

$$L_1= \frac{L_i - (r_j + t) \sin \theta_1}{\cos \theta_1} + (r_j + \frac{t}{2}) \theta_1 \quad (3)$$

$$L_2= \frac{L_o - (r_j + t) \sin \theta_2}{\cos \theta_2} + (r_j + \frac{t}{2}) \theta_2 \quad (4)$$

Groove for Installing Forward Lug

Groove width equations of inside and outside are obtained separately. The groove should be carefully cut because the groove width has to be fitted to rim diameter for welding.

The distance from the center line of a jig to the end of groove where rim comes in contact, has to be the same as rim radius in both sides. From Fig.4 , in the case of inside lug, d_r can be expressed as follow:

$$\frac{1}{2} d_r= (r_j + \frac{t}{2}) \sin \theta_1 + x\cdot \cos \theta_1 - \frac{t}{2} \sin \theta_1 \quad (5)$$

where

d_r = rim diameter

Solving Eq. (5) for x:

$$x = \frac{d_r - 2r_j \cdot \sin \theta_1}{2\cos \theta_1} \quad (6)$$

The inside groove width w_i can be expressed as:

$$w_i = (r_j + \frac{t}{2}) \theta_1 + x \quad (7)$$

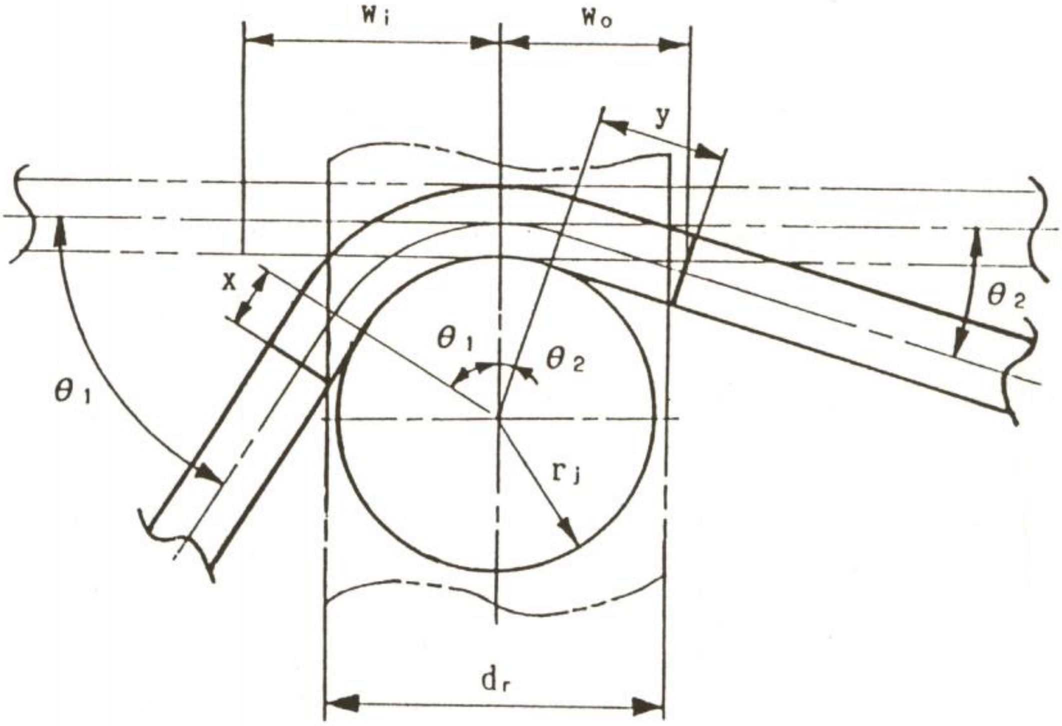

Figure 4 Details of groove width

Substituting Eq. (6) into (7), w_i can be obtained as:

$$w_i = (r_j + \frac{t}{2})\,\theta_1 + \frac{d_r - 2r_j \cdot \sin\theta_1}{2\cos\theta_1} \qquad (8)$$

Consequently, the outside groove width w_o is obtained as the same method as inside lug.

$$w_o = (r_j + \frac{t}{2})\,\theta_2 + \frac{d_r - 2r_j \cdot \sin\theta_2}{2\cos\theta_2} \qquad (9)$$

Groove Curve

The curves of the groove can be approximated to ellipses as shown in Fig.5, but these should be carefully designed and machined because they effect lug height as lug plates are welded with specified lug installing angle. The curve equations as ellipses of inside and outside lugs are also obtained separately. The ellipse equation of the inside lug groove can be expressed as:

$$(\frac{x}{w_i})^2 + (\frac{y}{R_{Li}})^2 = 1 \qquad (10)$$

where

R_{Li} = ellipse radius of inside lug

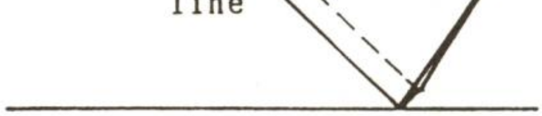

Figure 5 Ellipse radius of inside lug

R_{Li} of the radius of y direction in plane coordinate system has to be obtained. From Fig.5 , R_{Li} can be expressed as:

$$R_{Li} = \frac{d_r}{2\sin\alpha_f} - \frac{g_i - t(1 - \cos\theta_1)}{\tan\alpha_f} \qquad (11)$$

where

g_i = width of groove curve

α_f = installing angle of forward lug

The g_i can be obtained from geometrical analyses as:

$$g_i = (r_j+t)\,(1-\cos\theta_1)+(\frac{d_r}{2} - r_j \sin\theta_1)\tan\theta_1 \quad (12)$$

Substituting Eq. (12) into (10) and solving for R_{Li}

$$R_{Li} = \frac{d_r}{2\sin\alpha_f} - \frac{r_j\,(1-\cos\theta_1)+(\frac{dr}{2} - r_j\cdot\sin\theta_1)\tan\theta_1}{\tan\alpha_f} \quad (13)$$

The ellipse equation of the outside lug groove can be expressed as:

$$(\frac{x}{w_o})^2 + (\frac{y}{R_{Lo}})^2 = 1 \quad (14)$$

R_{Lo} can be obtained as the same method as inside groove:

$$R_{Lo} = \frac{d_r}{2\sin\alpha_f} - \frac{r_j\,(1-\cos\theta_2)+(\frac{d_r}{2} - r_j\cdot\sin\theta_2)\tan\theta_2}{\tan\alpha_f} \quad (15)$$

THE WHOLE PLANNING DESIGN

In order to obtain better plowing performance of a walk-behind tiller plow and iron

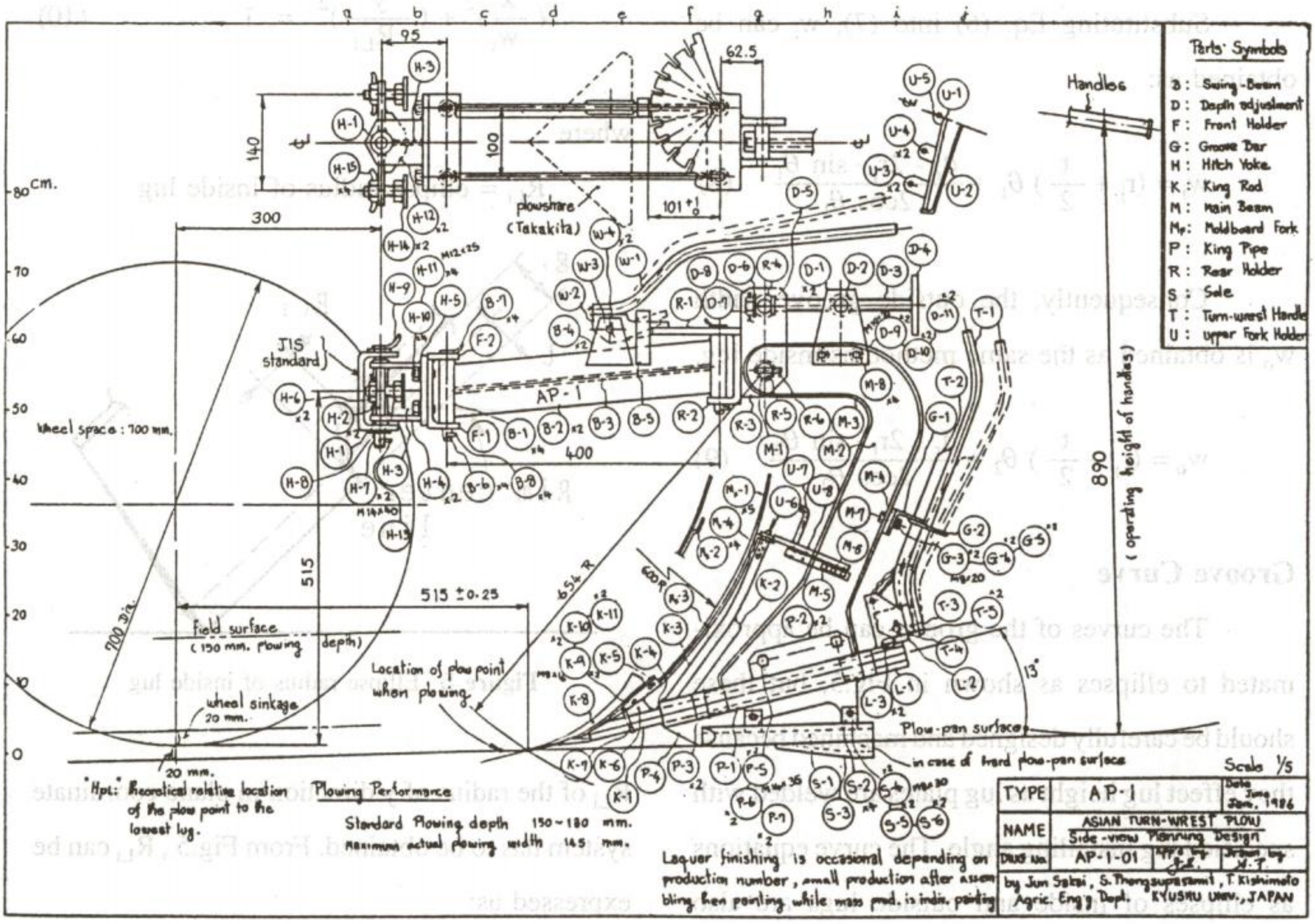

Figure 6 Side-view planning design of Asian turn-wrest plow and plowing wheels

wheels, a designer should consider the whole machines which are involved in plowing. Moreover, it is necessary for human engineering to be considered in designing in order to allow the operator to perform works with efficiency, safety and the least fatigue. Fig.6 shows a side-view of the whole planning design. The plow and iron wheels are designed from the mathematical design equations with many parameters of machine specifications, including plowing and paddy field conditions [1], [6].

ASSEMBLY DRAWING OF PLOWING WHEEL

The optimum structure and special shape of plowing wheel lugs can be obtained from design equations which are expressed from many parameters of the whole machines. These mathematical design equations of lug were already discussed in the previous paper [1].

Fig.7 shows the assembly drawing of the plowing wheel. The wheel structure and the shape of lug are designgd with the consideration of the whole machines.

SPECIFICATIONS OF DESIGNED PLOWING WHEELS

Detail drawings of parts for plowing wheels are performed according to its assembly drawing. Afterwards, all parts are made as shown in Fig.8 and are assembled tegether to form of the the plowing wheel as shown in Fig.9.

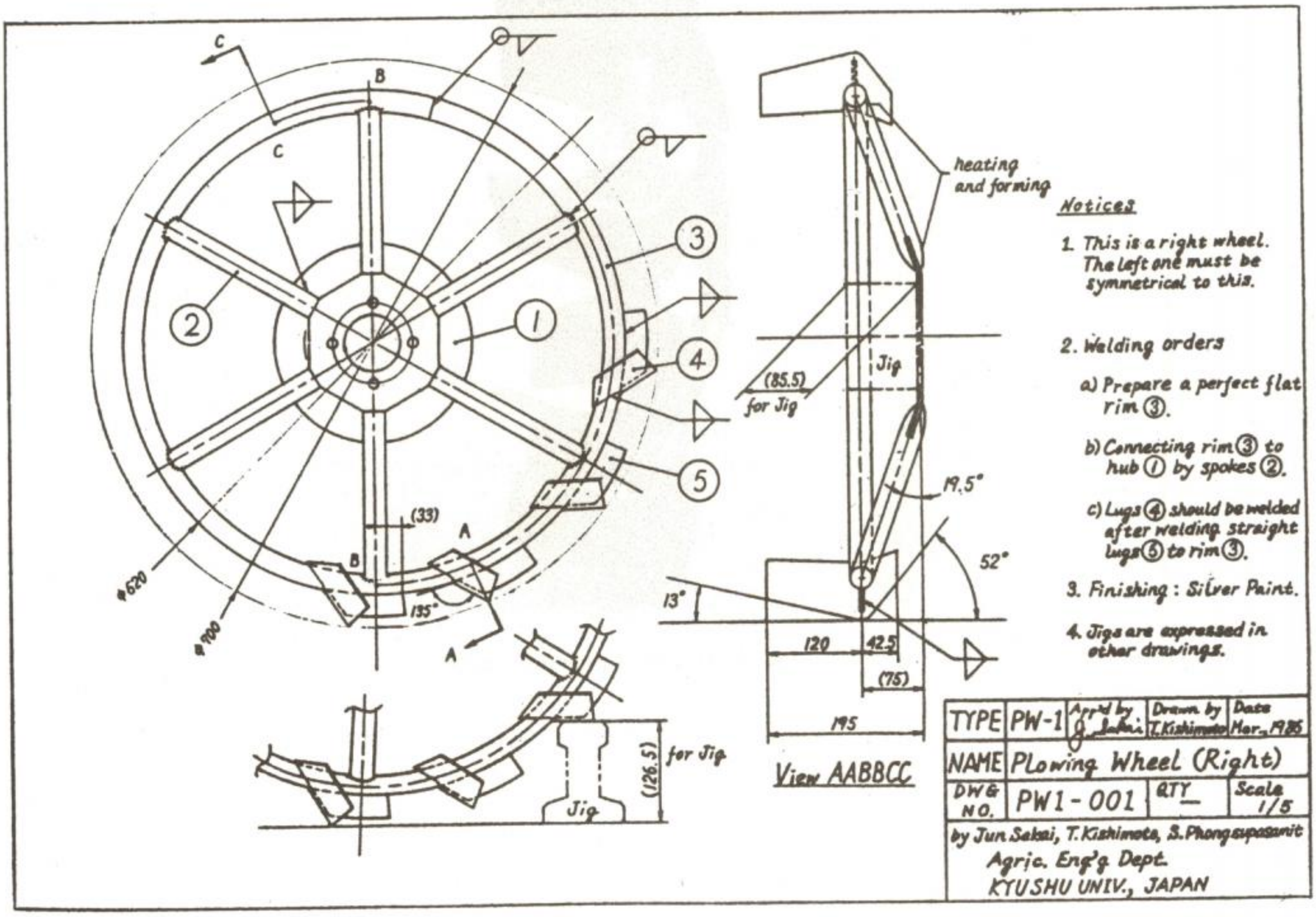

Figure 8 Parts of plowing wheel

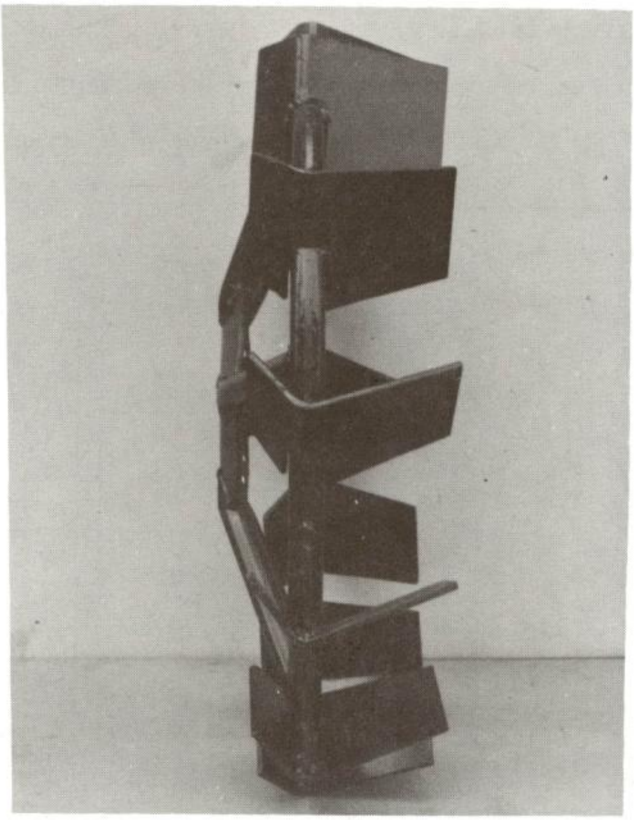

Figure 9 Designed plowing wheel

Some specifications of the designed plowing wheels campared to those of theoretical plowing wheels [1] are shown in Table 1.

FUNCTIONAL TEST RESULTS

The basic functional tests of plowing wheels are conducted in four plots of paddy fields.

Table 1 Comparison of specifications between theoretical and designed plowing wheels.

Items	Theoretical Wheel [1]	Designed Wheel
	Units	Units
Outside diameter	$\geqq$ 620 mm.	700 mm.
Number of spokes	4 - 6	6
Number of lugs	12 (at 15% slip)	12
Installing angle of forward lug	45 degrees	45 degrees
Outside lug width	$\leqq$ plowing width	120 mm.
Inside lug width	< 120 mm. (at max. plowing depth 150 mm.)	42.5 mm.
Outside lift angle	13 degrees	13 degrees
Inside lift angle	52 degrees	52 degrees

Table 2 Summary results of functional tests

Province	Total Weight of Machines (kg)	Cone Penetrating Resistance at 150 mm. (kg/cm^2)	Plowing Speed (m/s)	Plowing Depth (mm.)	Plowing Width (mm.)	Wheel Slip (%)
Suphanburi						
Walk-behind Tiller (1)	276.5	3.00 (M.C. 36.4%)	0.984	151	269	17.14
Walk-behind Tiller (2)	295.0	2.33 (M.C. 38.9%)	0.938	148	265	13.21
Nakornratchasima						
Walk-behind Tiller (1)	276.5	3.78 (M.C. 28.3%)	0.890	156	281	20.52
Walk-behind Tiller (2)	295.0	2.11 (M.C. 23.5%)	0.951	168	248	20.80

Each of two plots is located in Suphanburi and Nakornratchasima provinces. The plowing wheels and the Asian turn-wrest plows are installed on two medium size of walk-behind tillers with 8.5 rated horsepower engines. Soil conditions of fields are examined by using SR-2 soil resistance tester and soil moisture contents are also determined.

The summary of average testing results is shown in Table 2.

During plowing, it is observed that the lower wheel moves in the furrow and its outside lugs and inside lugs move into contact with furrow bottom and furrow wall respectively. Moreover, the lugs of the wheel do not move on the plowed soil as shown in Fig.9.

Furthermore, the operator can conveniently handle the walk-behind tiller in plowing and also free-hand plowing can be achieved as shown in Fig.10.

Figure 9 Lugs of lower wheel in furrow

Figure 10 Plowing with walk-behind tiller

It is shown that the whole planning design theories of plowing wheels, plows, walk-behind tillers with human engineering are necessary and should be developed. Then, these design theories can be applied to actual design practices like in the case of plowing wheels

CONCLUSIONS AND RECOMMENDATIONS

1. The wheel slip of designed plowing wheels are approximately equal to 15% except the wheel slip measured in Nakornratchasima. This may be due to the exceed plowing depth and plowing width. However, the wheel slip can be reduced by adding an optimum ballast to wheel axles.

2. Designers for plowing wheels have to consider not only the wheel structures but also the walk-behind tiller and the plow in order to achieve efficient plowing.

3. In order to assist the wheel engineering, some important parts' names and dimensions of the plowing wheels are proposed (Fig.1).

4. The forward lug of plowing wheel has a special geometrical shape so as to fit into furrow bottom surface (plowed pan surface) and furrow wall for stable motion of the walk-behind tiller.

5. The groove widths of inside and outside lugs are designed and calculated from diameter of a jig for lug plate bending, thickness of the plate, bending angles and so on. The groove of a lug plate has to be carefully designed and fabricated in order to fix lugs accurately to the rim.

6. The groove curves are also calculated from the dimensions of the lug plate and the jig. The curves can be approximated to different ellipses between the inside and the ontside lugs. These curves have to be machined accurately because the shape of ellipses effects the lug height at welding.

7. Cage wheels are generally designed for harrowing on upland fields and puddling on mud soil of paddy fields. However, cage wheels with narrow width may be used as plowing wheels on hard surface of paddy fields.

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