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DESIGN AND TRACTION PERFORMANCE OF MOVABLE LUG WHEEL EQUIPPED WITH LUG-SPRING MECHANISMS

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ABSTRACT

A movable lug wheel has been designed to improve the traction performance of two-wheel tractor in wet rice field. Each lug-plate of the lug wheel was equipped with lug-spring mechanisms so that the lug-plate could swing to the optimum inclination angle for producing the bigger traction force. The movable lug wheel was 85 cm in diameter, had 14 lugs (8 cm width × 35 cm length) which was equipped with a pair of torsion type springs. A set of field test has been conducted using a two-wheel tractor equipped with the movable lug wheel for plowing a wet rice field plot in Cianjur District, West Java. The test result showed that the movable lug wheel had a better traction performance than the conventional lug wheel. The average wheel slip of the movable lug wheel was 11%, which was lower than the wheel slip of the conventional lug wheel (21%). The swing action of the movable lugs could remove the adhered soil on the lug plates, and eliminated soil blocking between the lugs. The average of plowing efficiency using the movable lug wheel was 76%, which was bigger than the conventional lug wheel (68%).

INTRODUCTION

To improve traction performance and overcome mobility problem of two wheel tractor in lowland rice field operation, it is necessary to develop a new concept of lug wheel. As the result of previous researches [1, 2, and 3], a new concept of movable lug wheel had been developed and showed a better traction performance than the conventional (fixed) lug wheel. Using rollers and a sliding groove mechanism, the lug plate of the movable lug is held in a certain constant inclination angle to the horizontal soil surface during the contact period with soil to produce better pull and lift forces and also eliminate soil blocking over neighboring lug plates. It was found that the pull and lift forces obtained by the flat movable lug with 45° lug inclination angle was higher than those by the fixed lug [3]. A spring mechanism for the lug motion mechanism of the movable lug wheel then was introduced and evaluated [4]. The mechanism was designed to fit the best lug motion pattern that was founded by Hermawan et al. [3]. The test result showed that in comparison with the conventional fixed lug wheel, the lug wheel equipped with spring – lug mechanisms has a great potential for better traction and flotation.

The movable lug wheel with spring mechanisms should be applied in the real operation of two wheel tractor in wet rice filed of rice production area such as Cianjur District, West Java. For that purpose, the movable lug wheel should be designed based on the actual rice field condition, tractor and tillage implement used.

The objective of this research was to design and test a movable lug wheel equipped with spring mechanism for a hand tractor in tillage operation of wet paddy field.

RESEARCH METHOD

Measurement of soil condition and tractor specification

In order to design the proper movable lug wheel that meet the soil condition and tractor specification, the soil condition of wet paddy field in Cianjur District was measured, and the specification of the hand tractor used in that area was identified. The soil resistance on the plate penetration was measured using a penetrometer equipped with a steel plat at the tip and supported by inclination setting support base (Figure 1).

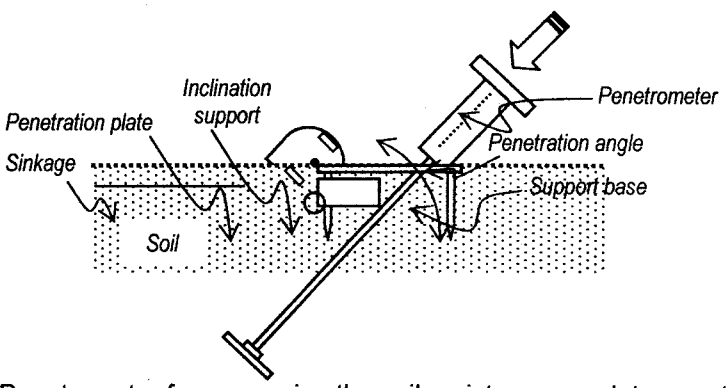

Figure 1. Penetrometer for measuring the soil resistance on plate penetration.

Using this apparatus, the inclination angle of plate penetration could be set to measure the soil resistance on the plate penetration on penetration angle of 30°, 45°, 60°, 75° and 90°. Three sizes of plate were used, i.e. a) 5 cm x 7 cm, b) 7.5 cm x 5 cm, and c) 10 cm x 5 cm. The soil resistance was measured on the depth of 2.5 cm, 5 cm, 7.5 cm, 10 cm, 12.5 cm and 15 cm. Furthermore, specification of a hand tractor used on the experiment area was identified. Tractor weight, wheel flange size and wheel bolt position, and relative position of gear box base and engine starter crank to the wheel axle were measured and identified.

Movable lug wheel design analysis

Design parameters of the movable lug wheel such as: a) lug plate size, b) spring coefficient for the spring mechanism, c) wheel diameter, and d) number of lug plate, were determined using the appropriate data obtained. In addition, the basic formation of two wheel tractor during paddy field plowing operation (Figure 2) and the ground clearance should be considered, in determining the wheel size.

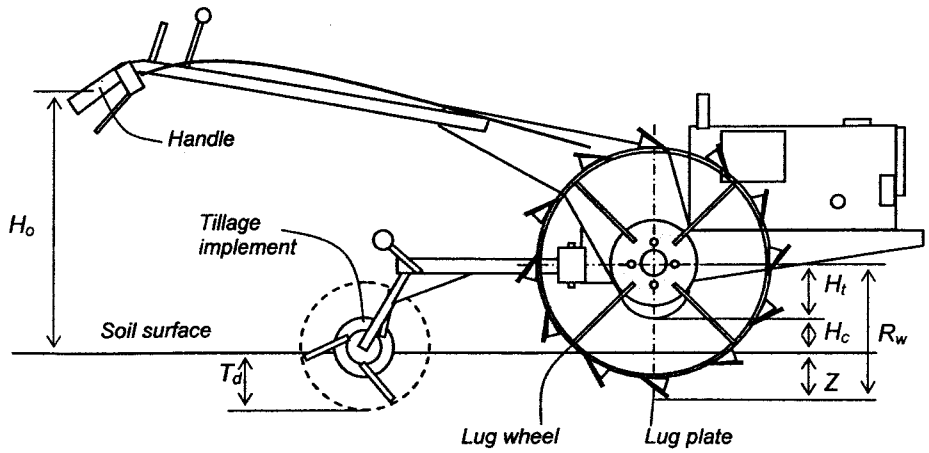

Figure 2. Basic formation of two wheel tractor during paddy field plowing operation.

Then, the movable lug wheel was designed using the following steps [5]: (a) determining the outer diameter of the lug wheel; (b) determining lug number; (c) determining lug plate size and lug plate material; (d) designing the spring mechanism for the movable lug; (e) determining spring size and material; (f) planning number, outer diameter and material of rim; (g) planning shape of wheel spokes and their size and material; (h) designing the wheel flange; (i) planning the arrangement of spokes, wheel flange, rims and rims connecting bars.

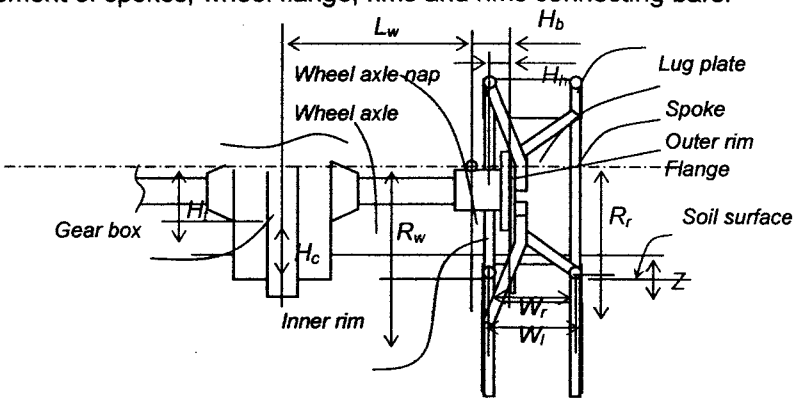

Figure 3. Lug wheel components and schema for determining the wheel size.

According to Figure 3, the outer wheel diameter R_w can be determined by

$$R_w = H_t + H_c + Z \quad (1)$$

where: H_t is the radius of the gear box, H_c is ground clearance, and Z is wheel sinkage. Then, wheel diameter is:

$$D_w = 2R_w \quad (2)$$

In addition, the maximum diameter of the wheel is limited by clear space for the wheel rotation which is bordered by engine starter crank at the front side and

tillage implement at the rear side. These dimensions should be measured on the tractor used in the area.

Lug plate size then should be determined precisely considering the relationship of the pull force, vertical load, wheel diameter, lug number, lug plate size, and wheel sinkage. The data of soil resistance on plate penetration was used to determine the lug plate size. In the design analysis, the horizontal component of the resultant of soil reaction forces on the active lug plates (working lugs) should be bigger than half of the pull force ($\frac{P_i}{2}$) and rolling resistance (F_{rr}). The vertical component of the resultant of soil reaction forces should be bigger than the vertical load supporting by the wheel ($\frac{W_t}{2}$).

$$\sum_{i=1}^{n} F_{sh} \geq \left(\frac{P_i}{2} + F_{rr} \right) \quad (3)$$

$$\sum_{i=1}^{n} F_{sv} \geq \frac{W_t}{2} \quad (4)$$

$$F_s = F_{sh} + F_{sv} \quad (5)$$

where: F_{sh} is horizontal component of the soil reaction force, F_{sv} is vertical component of the soil reaction force, and F_s is the resultant of soil reaction forces on the active lug plates.

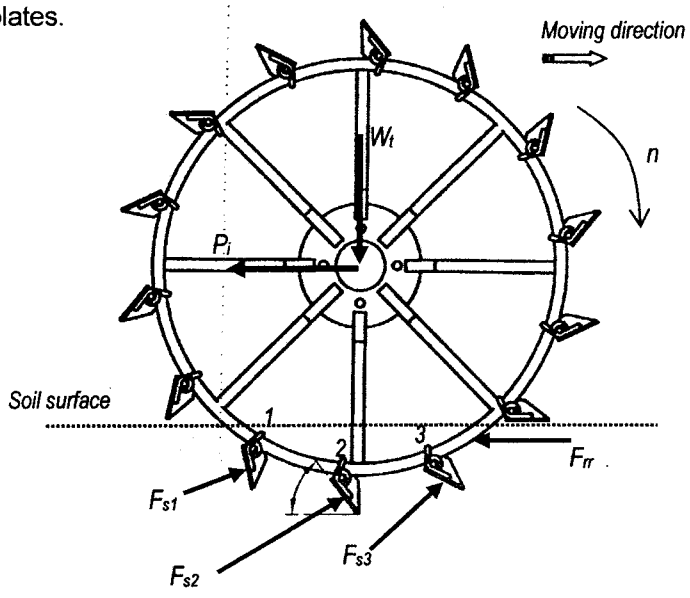

Figure 4. Working forces on the lug wheel.

Soil reaction forces on the active lugs F_{s1}, F_{s2}, F_{s3} etc. were calculated using the data of soil resistance to the plate penetration, according to the depth of the corresponding lug plate (lug position in the soil) and its inclination angle.

$$F_{sn} = A_s T_{pn} \quad (6)$$

where: F_{sn} is soil reaction force on the nth lug plate, A_s is lug plate area, and T_{pn} is soil resistance on the nth lug plate (measurement result at the corresponding depth and inclination angle). From the soil reactions, the horizontal and vertical components then can be determined accordingly.

$$F_{shn} = F_{sn} \cos\alpha \quad (7)$$

$$F_{svn} = F_{sn} \sin\alpha \quad (8)$$

where: F_{shn} is horizontal component of the soil reaction force on the nth lug plate, α is the inclination angle of the nth lug plate, and F_{svn} is vertical component of the soil reaction force on the nth lug plate.

Active lug number J_{sa}, lug plate size (lug plate area, A_s) and wheel sinkage Z are interrelated in achieving the force equilibrium on the wheel system. Then, the lug plate size was optimized and determined using the mentioned equations (3) - (8).

The spring mechanism for the movable lug plate (Figure 5) was designed in such a way that the lug plates can swing or deflect to make a 45° inclination angle by the soil reaction force on the lug plate. Therefore, the spring characteristic (size, spring constant and material) for the mechanism is determined by working forces equilibrium on the lug plate. As the lug plate was supposed to have a 45° inclination angle at its lowest position in the soil, the soil reaction force on the lug plate (according to the lug plate size and the wheel sinkage) was applied in designing the spring mechanism and determining the spring characteristic.

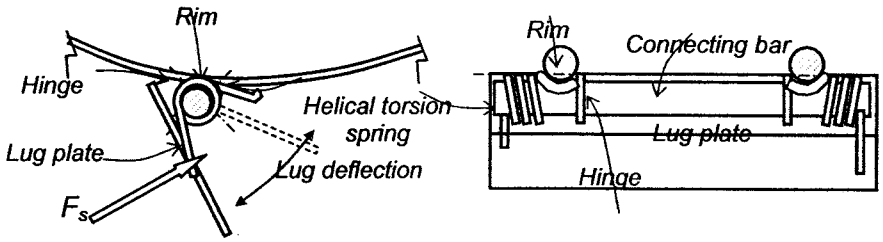

Figure 5. The spring mechanism for the movable lug wheel.

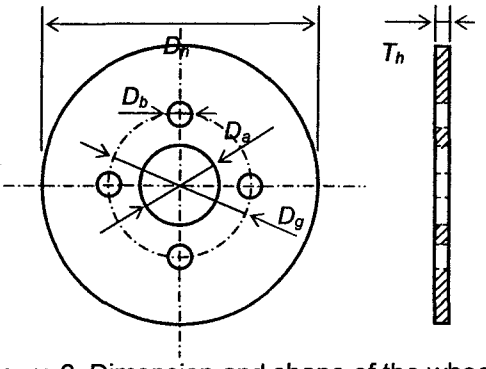

Figure 6. Dimension and shape of the wheel flange.

Wheel flange (Figure 6) is an important part of the lug wheel. Its size should be determined by the standard size of the wheel axle nap and its flange on the wheel axle of the tractor. Dimensions that should be determined are: flange diameter D_h, diameter of flange hole D_a, diameter of bolt hole D_b, circle diameter of bolt holes D_g, and flange thick T_h.

The number of wheel spoke depends on the wheel diameter, loads supported, and size and quality of the spoke. Number and size of the rim depend on the loads supported by the wheel.

Wheel performance test

Based on the design analysis, a pair of the movable lug wheels was fabricated. The prototype then was applied to the twc wheel tractor (local tractor) for paddy field tillage operation. The plowing operation using a mold board plow was conducted at three plots of wet paddy field in Cianjur District. The plot size was 25 m × 40 m. The same operation was also conducted using the conventional fixed lug wheel (local wheel). During the plowing operation, following field performances were measured: 1) effective field capacity and field efficiency, 2) wheel sinkage, and 3) wheel slip.

RESULTS AND DISCUSSION

The prototype of the movable lug wheel

As the result of the design analysis, the following design parameters had been determined: the wheel diameter was 85 cm; the number of lug plate was 14; lug plate width was 8 cm; lug plate length was 35 cm; lug plate thickness was 4 mm; lug angle was 36°; maximum lug plate deflection was 9°; rim material was 19 mm in diameter; and spoke material was 19 mm in diameter. Helical torsion spring was used for the spring mechanism of the movable lug, where pair of the springs was installed on each lug plate. The spring wire was 8 mm in diameter, the diameter of the coil was 19 mm, coil number was 3.1, and the distance of the load to the spring axis was 39.6 mm. Based on the design parameters, a pair of prototypes of the movable lug wheel (Figure 7) has been fabricated. The spring mechanism is shown in Figure 8.

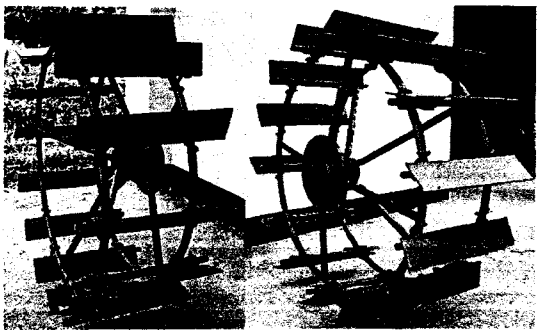

Figure 7. The prototype of the movable lug wheel

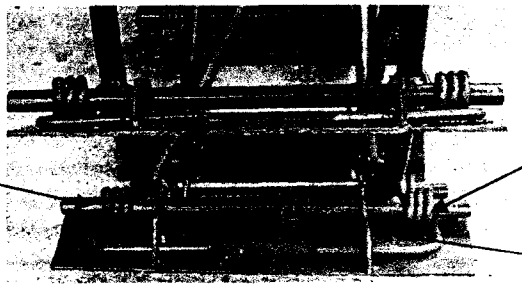

Figure 8. The spring mechanism of the movable lug.

The prototype had two rims installed 188 mm apart, had eight spokes (4 inner spokes and 4 outer spokes). The wheel flange was extended by a steel pipe to support the outer spokes. As the result of the optimum design, the wheel design has been corrected as shown in Table 1.

Table 1. Lug wheel design improvements

No.	Wheel design specification	Local lug wheel	Movable lug wheel
1	Wheel diameter (mm)	820	850
2	Lug plate area (cm^2)	217	280
3	Inter-rim distance (mm)	255	188
4	Wheel weight (kg)	30	50

The wheel working performances

Functional test showed that the wheel flanges of the wheel prototype could be installed properly to the wheel axle nap of the tested tractor, and the movable lug mechanism worked well, and the prototype could be utilized as a traction device for the tractor accordingly.

The result of the field test showed that the movable lug wheel performed better than the local fixed lug wheel. Average slip of the movable lug wheel was 11.54% which was lower than the average slip of the fixed lug wheel (20.89%). The average of plowing efficiency using the movable lug wheel was 76%, which was bigger than the conventional lug wheel (68%).

As observed on the performance test, the movable lug mechanism could improve the tractor mobility in the deep muddy paddy field. As the local fixed wheel sank deeper to about 20 cm depth, whereas the movable lug wheel could work well at about 15 cm sinkage. The lug plates of the movable lug wheel could deflect to the optimum inclination angle for attaining the bigger soil reaction forces. In contrast, as the wheel sank deeper, the rolling resistance became bigger and caused the poor mobility of the fixed lug wheel. Furthermore, as observed on the field test, the swing action of the movable lugs, as it departed form the soil, could remove the adhered soil on the lug plates, and eliminated soil blocking between the lugs (Figure 9 (b)).

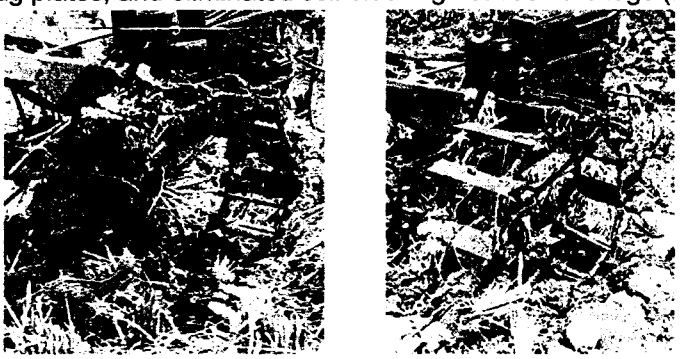

Figure 9. Soil blocking on the fixed lug wheel (a), and the swing action of the lug plate of the movable lug wheel which removed the adhered soil (b).

CONCLUSIONS

1. The movable lug wheel equipped with lug-spring mechanisms for a hand tractor in tillage operation of wet paddy field was designed and fabricated.
2. The movable lug wheel had a better traction performance than the conventional lug wheel. The spring mechanism of the movable lug wheel could improve the wheel mobility on wet paddy field. The swing action of the movable lugs could remove the adhered soil on the lug plates, and eliminated soil blocking between the lugs.

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