



ANALYSIS OF VERTICAL FORCE ACTING ON A LUG WHEEL OF A POWER TILLER

(Analisis Gaya Vertikal pada Sirip Roda Besi Traktor Tangan)

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ABSTRACT

Analysis of vertical force acting on a lug wheel of traction aid is very important prior in designing traction aid of agricultural vehicles in paddy fields. This study was conducted for a single cage wheel in the soil bin by using testing rig/trolley. A special transducer was developed to measure the vertical force acting on a lug wheel. The experiments were conducted for different number of lugs on a wheel and different pull force. In addition, dynamic vertical force measurements resulted was compared with the predicted value. This study concluded that for all variations of lug number and pull force, initially the dynamic vertical force acting on a lug increased up to a certain degree, and after attaining a peak value, it decreased continuously to a negative value or zero just before the lug left the soil. For all pull forces applied, the peak values were obtained almost at the same rotation angle of the lug. At different number of lugs, the dynamic vertical force acting on each lug position increased as pull force was increased. The total dynamic vertical force for the wheel with 18 lugs increased sharply as pull force increased compared to the wheel with 14 and 16 lugs.

Key words: vertical force, lug wheel, analysis.

ABSTRAK

Analisis gaya vertikal yang bekerja pada sirip roda besi traktor tangan adalah penting sebagai parameter rancangan alat bantu traksi pada kendaraan yang bekerja di lahan sawah. Penelitian ini dilaksanakan dengan menggunakan satu buah roda besi traktor tangan di soil bin dengan menggunakan spesial testing rig yang dirancang untuk pencapaian tujuan penelitian. Sebuah transducer dirancang khusus untuk mengukur besarnya gaya vertikal yang bekerja pada sirip roda. Percobaan pengukuran gaya vertikal dilaksanakan pada berbagai jumlah sirip roda dan berbagai gaya penarikan horizontal. Sebagai tambahan, gaya vertikal dinamis terukur dibandingkan juga dengan nilai nilai perkiraan. Hasil dari penelitian ini menyimpulkan bahwa untuk variasi jumlah sirip dan gaya tarik horizontal, pada awalnya gaya vertikal dinamis meningkat sampai nilai tertentu, dan setelah mencapai nilai maksimum tertentu, nilai nilai tersebut menurun secara continue sampai ke titik nol dan bahkan negative. Untuk variasi gaya penarikan horizontal, nilai maksimum dicapai hampir pada posisi rotasi roda yang sama. Pada variasi jumlah sisip roda, gaya vertikal dinamis meningkat dengan meningkatnya gaya tarik horizontal. Total gaya vertikal dinamis roda dengan jumlah sirip 18 meningkat sangat tajam dengan meningkatnya gaya tarik horizontal dibandingkan roda dengan jumlah sirip 14 dan 16.

Kata Kunci : gaya vertikal, sirip roda besi, analisis

INTRODUCTION

A study on vertical force acting on lugs wheel of a power tiller is very essential prior to the designing of a traction aid of agricultural vehicles in paddy fields. This study aimed to

Give important information and guidance on designing a traction aid of agricultural vehicles.

Traction may be defined as the force derived from the interaction between a device and a medium that can be used to facilitate a desired motion over the medium. A useful traction device converts rotary motion from the

engine into useful linear motion. The total engine power available for conversion into useful pull is generally in excess of the traction capacity developed between the traction device and soil. The efficiency with which a traction device converts energy into pull is usually poor when the device is operating on soil, especially wet soils.

As the rigid wheel is operating on deformable soils, sinkage occurs and deformation of the soil results. With accurate stress-strain relationship and parameters which describe dynamic properties of soil, the boundary condition on strain (which must coincide with the shape of the wheel) and the boundary condition on stress (which must be equal to the weight on the wheel) can be imposed and a solution can be obtained. Thus, the stress-strain equation of the soil, dynamic properties of the soil, geometry of the wheel are required to study to solve the traction problems (Gill and Glen, 1967).

Yu and Kushwaha (1994) found that the dynamic load of a tractor is an important variable in the tractive performance of wheeled vehicles. Dynamic load affects the maximum traction generated by drive wheel, tractive efficiency and motion resistance. Under good tractive conditions, traction increases with an increase of dynamic load. Tractive efficiency increases with an increase in the dynamic load in compacted soil, and decreases with an increase in dynamic load on loose soil. For a single wheel, Burt and Bailey (1982) stated that the tractive efficiency could be improved by 10 to 12% by optimizing the levels of dynamic load. For maximizing tractive efficiency, the drawbar load should be approximately 50% of the total dynamic load (Bashford, 1985).

Salokhe et al. (1990) studied the pull and lift force on multiple cage wheel lugs when operated in wet clay soil. The objective of this study was to find the force characteristics under multiple cage wheel lugs. Two flat plate lugs with a 30 deg lug angle were used in this study. These lugs were installed in sequence for preceding and succeeding lug. The soil moisture contents and cone index values selected were 40% (d.b.) (CI = 150 kPa), 50% (d.b.) (CI = 120 kPa) and flooding was 65% (d.b.) (CI = 60 kPa). It was concluded that the normal force and pull force on the preceding and succeeding lugs showed almost the same trend. However, in all cases, the normal and pull forces of the preceding lug were higher than the normal and pull forces of the succeeding lug. The tangential

force of both lugs did not show much difference. The lift force of the preceding lug was higher than that of the succeeding lug. As the total wheel forces of the cage wheel are a summation of individual lug forces, the lug spacing and slip will play a significant role in designing a cage wheel. Pull and lift forces at 36 deg lug spacing were higher than those at 30 deg lug spacing. Increasing sinkage from 4 to 8 cm significantly increased pull and lift force.

Wang et al. (1995) studied the characteristics of soil reactions of an open lugged wheel under paddy soil conditions. From their experiment using the free sinking method at 19% and 41.2% (d.b.) of soil moisture content, the pull and lift forces of the lugged wheel fluctuated periodically with lugged wheel rotation, corresponding to the angle between adjacent lugs. Consequently, there was a fluctuation in the slip and sinkage of the lugged wheel.

Hermawan et al. (1998) evaluated the performance of movable lug wheels with two types of lug moving patterns in a soil bin. The results confirmed that sinkage, slip and torque of the movable lug wheel and the fixed lug wheel fluctuated periodically with the rotation angle of the wheel, and the period corresponded to the angular lug spacing. These fluctuations decreased by decreasing the angular lug spacing. Under the same level of vertical load, the fixed wheel sank more than the movable lug wheel. However, under various horizontal loads, there was no significant difference in slip between the movable and fixed lug wheel. Among both types of movable and fixed lug wheels, the movable lug wheel required lower torque and developed higher tractive efficiency.

An effort was made by Watyotha et al. (2001) to introduce the new design of cage wheel for power tillers, named opposing circumferential lugs. In order to find optimum design of this type of cage wheel, the effect of the circumferential angle, lug spacing and slip on lug wheel forces were studied in a laboratory soil bin filled with Bangkok clay soil at 51% (d.b.) moisture content. The forces measured in this study were horizontal, lift and side forces. The circumferential angle was varied from 0, 15, 30 to 45 deg. The lug spacing and wheel slip were varied from 20, 30 to 40 deg and 20, 35 to 50% respectively. All the force measurements were done at a constant sinkage of 7 cm. It was found that the change of circumferential angle had a little effect on pull force and lift force, while the side force was significantly affected. At 45 deg



circumferential angle, the side force was highest. Regarding the effect of lug spacing, it was found that at 20 deg, the pull force was highest, the maximum lift force was obtained at the lug spacing ranged from 20 to 30 deg and the side force decreased as lug spacing increased. For the effect of wheel slip, it was shown that at 35% slip, the wheel produced higher pull, lift and side forces compared to 20 and 50% wheel slip.

MATERIALS AND METHODS

The vertical force acting on a lug wheel was recorded using a specially developed transducer attached to a lug wheel on a special test rig/trolley (Fig 1) in the soil bin. The

transducer was developed by mounting four strain gauges of $60\Omega \pm 0.3$ with a gauge factor of $2.06 \pm 1\%$ on an iron bar (Fig. 2). As shown in Fig. 3, this transducer was mounted on the lug of the test wheel. Bending principle of the bar was adopted in the design of this transducer. The transducer and lug were arranged in such a position to ensure that when the lug is in contact with the soil, the force will be transmitted to the iron bar, and the bending force on both side of the bar can be recorded by the strain gauges. Calibration was conducted up to 1200 N load, and the results are presented in Fig. 4.

In this experiment, peat soil was compacted in the soil bin and flooded. The soil condition up to 40 cm depth was made as close as possible with the field conditions, in term of its bulk density and penetration resistance.

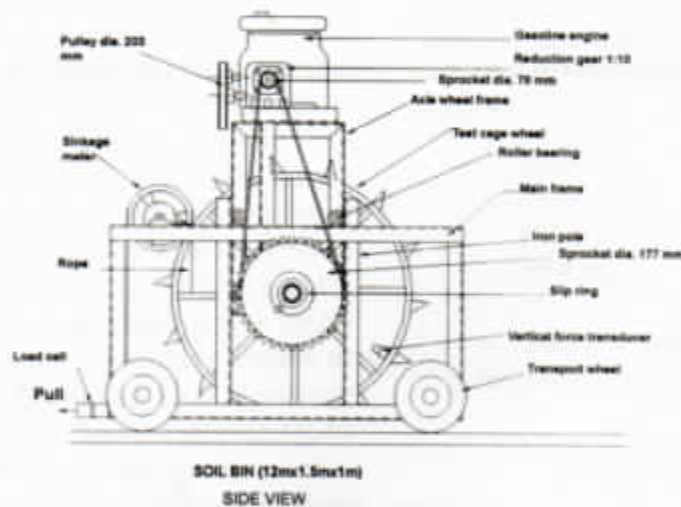


Fig. 1. Testing Rig/Trolley

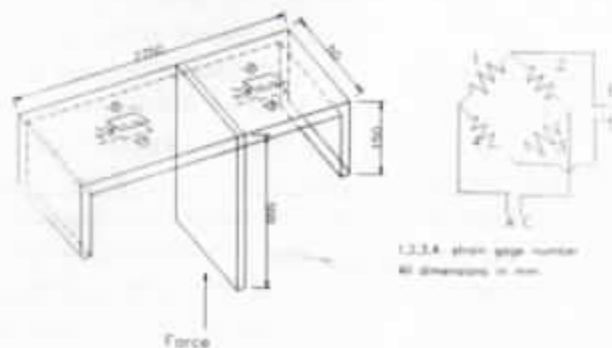


Fig. 2. Design of vertical force transducer, strain gauge installation and bridge circuit

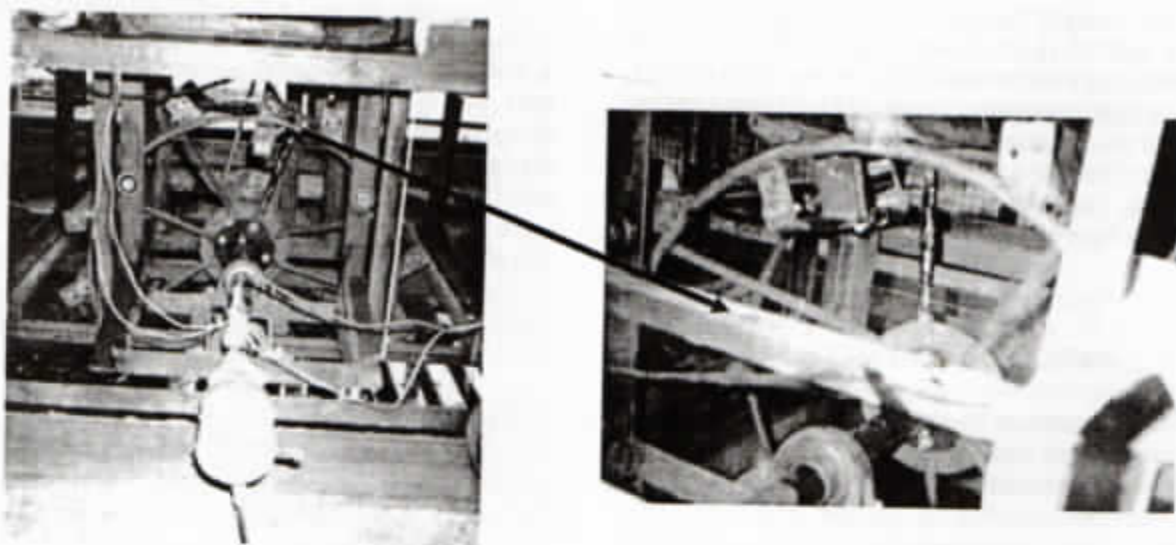


Fig. 3. Vertical force transducer installation on a cage wheel lug

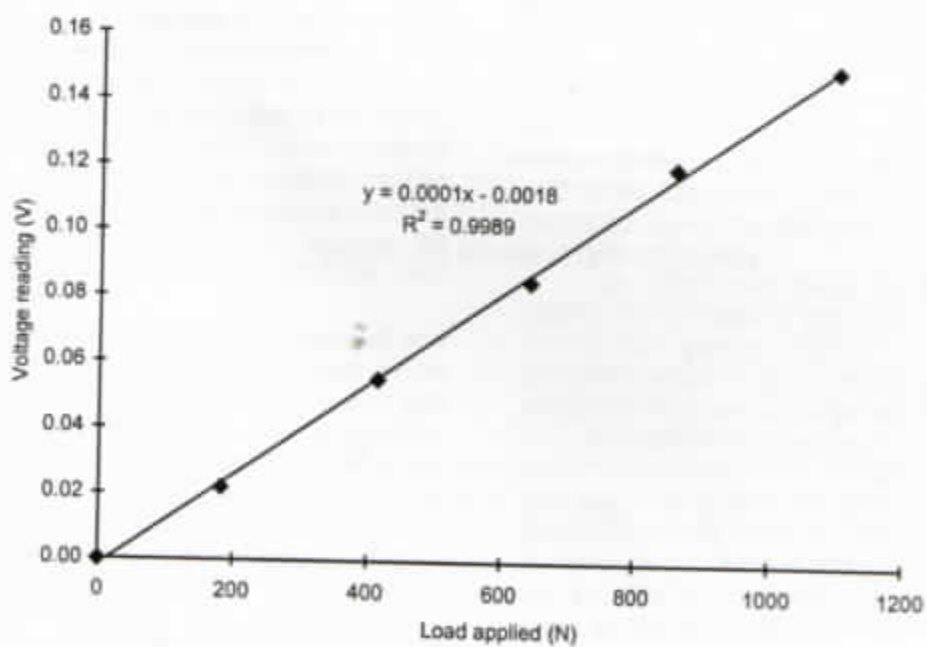


Fig. 4. Calibration curve of vertical force transducer



The experiments were conducted for variation number of lugs on a wheel and variation pull force applied. Number of lugs on a wheel were varied for 14, 16 and 18 lugs. At each number of lugs, pull was varied for minimum to maximum i.e 143.3, 225.5, 333.4 and 452.8 N. The dynamic vertical force was recorded on each position of a lug in contact with the soil.

RESULTS AND DISCUSSIONS

Fig. 5 shows the distribution pattern curves of the dynamic vertical force acting on each position of a lug in contact with the soil for the number of lugs 14, 16 and 18 (26, 22.5 and 20 deg), and pull forces of 143.3, 225.5, 333.4, 452.8 N. These force values were recorded by using the vertical force transducer developed as shown in Figs 2 and 3.

The curves show that for the number of lugs and pull force variations, initially, the dynamic vertical force acting on a lug increased up to a certain degree, and after attaining a peak value, it decreased continuously to a negative value or zero just before the lug left the soil. For pull forces applied, it was found that the peak values were obtained almost at the same rotation angle of the lug. Those were at 64, 67.5 and 60 deg for the wheels with 14, 16 and 18 lugs respectively. It was also found that because a part of the pull force was transferred into vertical force, the dynamic vertical force acting on each lug position increased as increasing pull force at all of the number of lugs on a wheel.

Due to the increasing number of lugs in contact with the soil, the peak values of the dynamic vertical force tended to decrease as the number of lugs increased from 14 to 16. It was found that these peak values were 638 and 567 N for the wheels with 14 and 16 lugs respectively. Increasing the peak values of the dynamic vertical force from number of lugs 16 to 18 was due to the effects of soil sticking on lugs. It was observed that due to the reduction of lug opening for the wheel with 18 lugs caused the soil to stick easily between the lugs. Increased volume of the soil stuck tended to increase the total of dynamic vertical force.

In order to evaluate the results obtained from this measurement, the dynamic vertical force was also calculated by using the method presented in Fig. 6.

The total dynamic vertical force obtained in these tests was compared with the calculation of the dynamic vertical force (W_d) using the method presented in Fig. 6. The dynamic vertical force was calculated based on the pull force applied on the drawbar of test rig/trolley (P), the normal load applied on the axle wheel tested (W), traction force in forward direction (F), rolling resistance (R), the distance between the center of the axle of the test wheel and center of the rear transport wheel O_1 (X_1) as a base line, the distance between the base-line and horizontal line of the pull force (X_2), and the distance between the base line and line of traction of F and R (X_3). The forces at equilibrium condition are as follows:

$$P = F - R \quad \dots(1)$$

$$W = W_d \quad \dots(2)$$

Taking the moment at O_1 , Eqs. to solve dynamic vertical force (W_d) are as follows:

$$W(X_1) + P(X_2) - (F-R)(X_3) = W_d(X_1)$$

Substituting $(F-R)$ with P , then

$$W_d = [W(X_1) + P(X_2) - P(X_3)]/X_1 \quad \dots(3)$$

The total dynamic vertical force acting on the axle of the test wheels was obtained by summing up of the vertical forces acting on each respective lugs position in contact with the soil. The comparison of total dynamic vertical force for the variation of the number of lugs is presented in Fig. 7. The figure shows that for the wheel with 18 lugs, the total dynamic vertical force increased more sharply as pull force increased compared to the wheels with 14 and 16 lugs. It was due to soil sticking between the lugs of the wheel with 18 lugs.

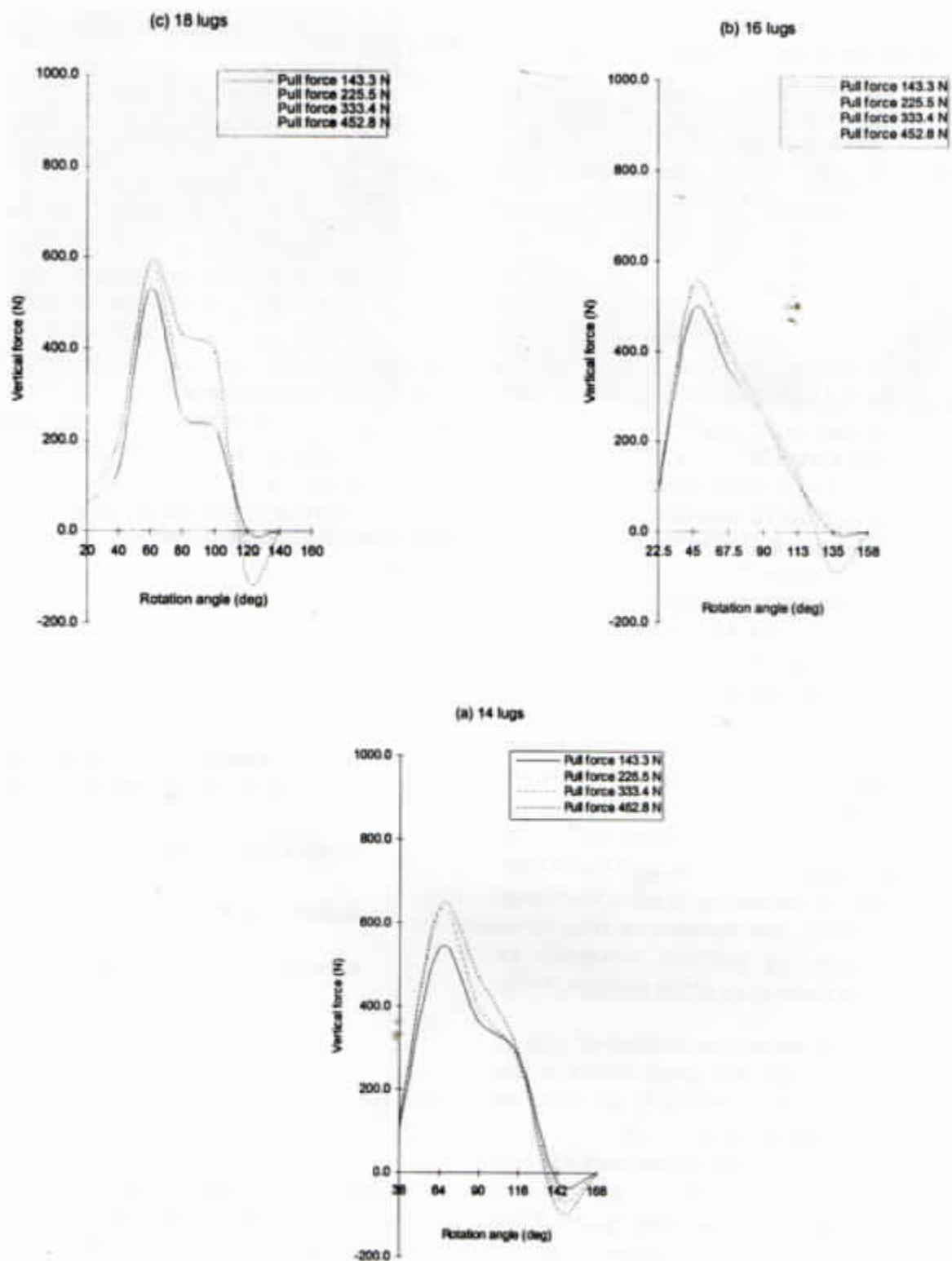


Fig. 5. The pattern of the vertical force acting at each lug position in contact with the soil for different Number of lugs and pull force

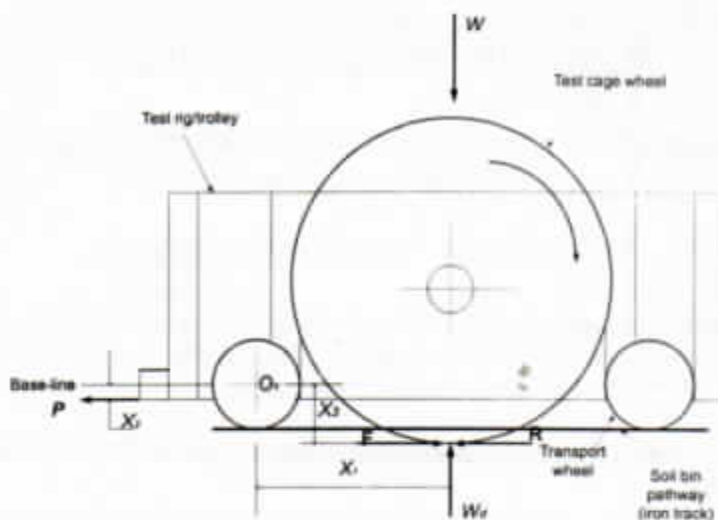


Fig. 6.: Method for calculation of the dynamic vertical force

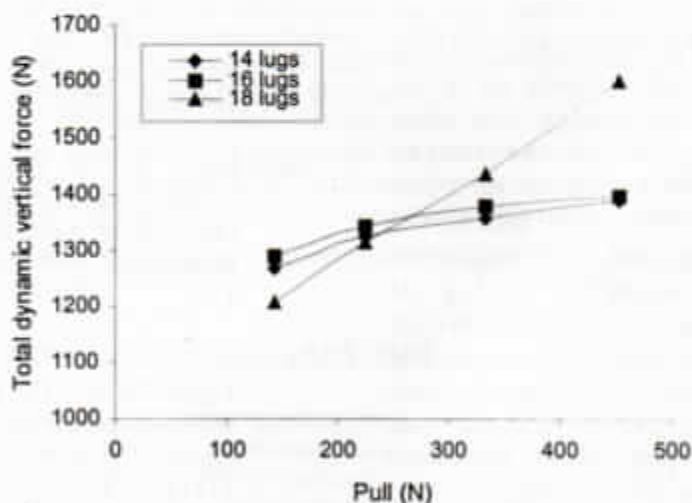


Fig. 7: Total dynamic vertical force measured at different number of lugs against pull

The results obtained for the cage wheel with 14 lugs were then compared with the results obtained from the measurement, as presented in Fig. 8. It shows that the results obtained from the calculation initially were relatively higher, then lower as pull increases compared to the measured results. The reason was that, at low levels of pull, the friction force between the main frame and the axle frame of

The test rig/trolley (Fig. 1) was neglected in the calculation method. At high levels of pull, the sticking soil on lugs of the wheel tended to increase the total vertical force which was also neglected in the calculation method. However the difference between the calculated and measured values was not much, it was only 6.1% in average.

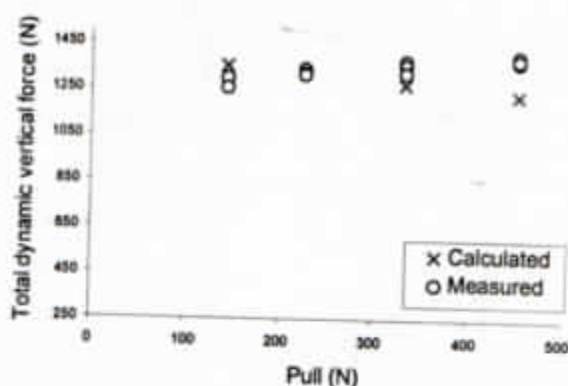


Fig. 8: Comparison of measured and calculated total dynamic vertical force for the cage wheel with 14 Lugs on a wheel

CONCLUSION

The analysis of the pattern of dynamic vertical force acting on each lug position in contact with the soil showed that for all variations of lug number and pull force, initially the dynamic vertical force acting on a lug increased up to a certain degree, and after attaining a peak value, it decreased continuously to a negative value or zero just before the lug left the soil. For all pull forces applied, the peak values were obtained almost at the same rotation angle of the lug. At different number of lugs, the dynamic vertical force acting on each lug position increased as pull force was increased. The total dynamic vertical force for the wheel with 18 lugs increased sharply as pull force increased compared to the wheel with 14 and 16 lugs. Compared with the results obtained from the calculation, the results obtained from the calculation initially were relatively higher, then lower as pull increases compared to the measured results. These results finding lead to the appropriate design cage wheel of a power tiller for use in swampy peat soils. The important finding that could adopted was the cage wheel with 16 lugs on a wheel.

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