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Effects of Lift Resistance on Dynamic Load acting on a Circular Wheel

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Abstract

The objective of this study is to measure contra-retractive adhesion and lift resistance acting on the rim section of a circular wheel for analyses of their effects on the dynamic load. A circular iron wheel was used for experiments. A part of the wheel rim was cut off, and transducers which can measure normal and tangential forces were installed in this section. Experiments were conducted on a laboratory soil bin which was filled with clayey soil under wet and dry conditions.

The mechanisms of generating contra-retractive adhesion on a circular wheel were analyzed by the experiments and motion analyses of the wheel. Effects of lift resistance on dynamic load were analyzed by measured forces under wet soil conditions in comparison with those under dry conditions. These showed that a part of the lift resistance were transferred to the dynamic load. These results may become basic data and ideas for analyses of tractor dynamics under wet soil condition.

[Keyword] agricultural wheel, tractor dynamics, dynamic load, lift resistance, contra-retractive adhesion,

1. Introduction

Gross traction, motion resistance and dynamic load have been analyzed in wheel engineering in the downward lug motion into soil. However, "contra-retractive adhesion" and "lift resistance" acting on lug surfaces to interrupt the wheel retraction from wet and sticky soil were proposed to exist through analyses in the upward motion of the lug(3)(4)(6). The existence of these forces on iron wheel lugs were proved by experiments(5)(6) through measuring them acting on these surfaces separately with newly designed transducers(2)(7).

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The maximum of contra-retractive adhesion ratio which is defined as the ratio of the maximum contra-retractive adhesion to the maximum reaction of the dynamic load, was about 0.2 of the maximum value on the lug face, and its influence was thought to be equivalent to that of the motion resistance(5)(6).

As the experiments were conducted with open rigid lugs for two-dimensional analyses, new forces above mentioned were measured only at the end of the action of each lug to the soil. However, lugs are installed on an undertread face by zigzag patterns in general in the case of agricultural pneumatic rubber tires. Therefore, those forces may be generated at lug faces continuously.

In order to analyze the characteristics of forces at the lug face, circular iron wheels were used for experiments. Transducers which can measure normal and tangential forces were installed to a wheel rim. As those transducers have three adjacent sensing elements, contra-retractive adhesion can be measured successively. Though a pneumatic tire is deformed from its structure, tire deformation has not been considered in this study as it is the first stage for the tire study.

2. Contra-retractive Adhesion and Lift Resistance

Fig. 1 shows the schematic diagram of external forces acting on a lug face from the motion analyses of it. The direction of the normal force on lug faces of both transport and traction wheels becomes slant backward as "Fn" in Fig. 1 when the lug face retracts from the soil. "Fn" in Figs. 1-a and 1-b are the "contra-retractive adhesion". Vertical components "$F_{bc}V$" of the resultant forces "F_{bc}" in Figures are the "lift resistance" on the lug face.

The direction of the tangential force becomes forward as shown in Fig. 1-a in the case of positive travel reduction of the wheel. The direction of the tangential force becomes backward as shown in Fig. 1-b in the case of negative travel reduction.

In both cases, the vertical components of the resultant forces become a part of the lift resistance of the whole lug. This force seems to contribute the greater part of total lift resistance on the whole lug when wheels are operated on clayey soil with shallow sinkage.

3. Apparatus and Procedure

3. 1 Rim Sectional Transducers

Fig. 2 shows the schematic view of rim sectional transducers installed to a tested wheel. Normal and tangential forces acting on a part of the wheel rim were measured independently by these transducers with strain gauges. As those transducers have three adjacent sensing elements, contra-retractive adhesion can be measured successively.

The motion resistance as a horizontal force and the reaction of dynamic load and the lift resistance as vertical forces were obtained from the measured normal and tangential forces. Those forces were calculated from following equations.

$$Fh = -Ft\cdot\cos(\theta+\gamma) - Fn\cdot\sin(\theta+\gamma) \quad (1)$$

$$Fv = Ft\cdot\sin(\theta+\gamma) - Fn\cdot\cos(\theta+\gamma) \quad (2)$$

θ : rotational angle
γ : transducer phase angle
(No.1 6° :No.2 0° :No.3 -6°)

3. 2 Apparatus

Fig. 3 shows the schematic view of a experimental apparatus. The apparatus consists of a carriage, trailing arms, a wheel mounting frame, a pulling wire, a tested wheel and a soil bin (length 1100 cm, width 85 cm, depth 45 cm).

The tested wheel is driven by a variable speed motor when it is operated as a positive travel reduction of the wheel, so called a traction wheel. The desired slip of the wheel can be obtained by the motor and a wire-pulling system. When the wheel is operated as a zero torque input of the wheel, so called a transport wheel, the motor is removed from the frame and it is operated by pulling the carriage with a wire-pulling system. The desired speed of the carriage is obtained by the arrangement of mechanical transmissions. Experiments were conducted with a transport wheel only in this study though tested wheels can be operated under two driving conditions as mentioned above.

The outside diameter of the tested wheel was 600 mm in this study. The rim sectional transducers are assembled and connected to the frame by an axis transducer(orthogonally holed cantilever type)[1] for measuring the motion resistance and the reaction of the dynamic load. A wheel rotational angle is detected by a photo-interrupter.

3. 3 Procedure

Experiments were conducted on a laboratory soil bin filled with loam in order to confirm the theory of lift resistance. Preparation of soil for experiments was done by rotary tilling, compacting and leveling after adding adequate water for desired moisture content. Tow conditions of soil moisture contents, about 18 % for wet condition and 13 % for dry condition in wet base, were prepared. Average cone indexes of the wet soil and the dry soil in 15 cm depth were 1.93 MPa and 1.97 MPa respectively.

Experiments were conducted under the zero torque condition as a transport wheel. The motor was removed from the frame and the tested wheel is operated by pulling the carriage with a wire and a winch. Traveling speed was kept constant about 0.1 m/s through experiments. Five stages of the dynamic load were obtained through applying additional weights to the wheel. Sinkage and wheel distance per revolution were measured after each experiment. Data from the rotational angle detector, the rim sectional transducers and the axis-transducer were recorded to a data-recorder. All recorded data were converted to digital signals by an A/D converter and processed by a micro-computer.

4. Results and Discussion

4. 1 Vertical Component of Resultant Force

Fig. 4 shows examples of the reaction of the dynamic load and the motion resistance measured by the axis transducer at the same additional weights. Table 1 shows the relationships between the motion resistance, the reaction of dynamic load and motion resistance ratio. The motion resistance ratio in the experiment on the dry soil is in the range of 0.05 to 0.10, and that on the wet soil is in the range of 0.10 to 0.15.

The mean values of vertical forces "FV" on the wet soil as shown in Fig. 4-a and on the dry soil as shown in Fig. 4-b are 983.7 N and 978.6 N respectively. Vertical force "FV" as the reaction of the dynamic load acting on the whole wheel on the wet soil is measured almost same as that on the dry soil.

Fig. 5-a shows examples of vertical components of resultant forces calculated from normal and tangential forces acting on rim transducers on the wet soil. The vertical force in Fig. 5-a becomes negative at the end of rim acting to the soil, though it is positive when the rim starts to act. It shows that the lift resistance is produced at the rim section by its retraction from the soil.

Fig. 5-b shows those on the dry soil. The vertical force in Fig. 5-b is positive from the beginning through ending of rim action to the soil. The lift resistance was not produced on the dry soil.

The lift resistance occurs especially under wet and adhesive soil condition such as Asian lowland-paddy field. The influence of lift resistance is thought to be little under dry soil condition such as upland field.

4. 2 Lift Resistance Ratio

The ratio of the maximum contra-retractive adhesion to the maximum reaction of the dynamic load is defined as "contra-retractive adhesion ratio", as the contra-retractive adhesion acting on a lug face is thought to contribute the greater part of the lift resistance when a lugged wheel is operated on clay or clayey soil with shallow sinkage. "Lift resistance ratio" is also defined as the ratio of the maximum lift resistance to the maximum reaction of the dynamic load on a lug surface[4)6)].

The lift resistance ratio calculated using the measured value on the rim section was smaller than that on the lug face of the open lug, but it was in the range of 0.07 to 0.10 as shown in Table 2. This means that the influence of the lift resistance on the circular wheel is almost equivalent to that of the motion resistance.

4. 3 Superposition of Vertical Force and Load Transfer

The lift resistance is produced at the rim section by its retraction from the soil. As the lift resistance is negative force, it is thought to be transferred from the lifting part to the rim contact area in the soil. Therefore, the vertical force may be increased by its transfer.

Positive component and negative one of the vertical force are superposed separately for one wheel rotation. The positive component becomes the reaction of the dynamic load, and the negative component becomes the lift resistance.

Fig. 6 shows the result of the superposition of vertical forces measured by the rim transducers. The reaction of the dynamic load obtained by the superposition of the positive component of the vertical force becomes larger than that of measured by the axis transducer. This increased reaction of the dynamic load can be named the reaction of <u>gross dynamic load</u>, and the force measured by the axis transducer can be named that of <u>net dynamic load</u>. The superposition of the negative component of the vertical force shows the generation of the lift resistance which is produced by the rim section continuously at the end of rim action to the soil. Fig. 7 shows the superposition of the lift resistance to the <u>gross dynamic load</u>. Total force becomes almost same as the <u>net dynamic load</u> measured by the axis transducer. Then, this phenomena is proved to be caused by the lift resistance transfer.

The phenomena is thought to be similar to the weight transfer of the tractor and the lift resistance is thought to be one component of the dynamic load, so that this phenomena is proposed to be named <u>wheel internal load transfer</u>. These results become ideas for analyses of tractor dynamics such as weight transfer theories under wet soil condition as the paddy field. The <u>wheel internal load transfer</u> may be closely related to the magnitude of lift resistance, contact area, sinkage and dynamic load. Detail analyses for relationships between each parameter will be reported in other scientific paper.

5. Conclusions

"Contra-retractive adhesion" was measured with rim sectional transducers of a circular iron wheel for modeling lug faces of agricultural pneumatic rubber tires. Effects of "lift resistance" calculated from contra-retractive adhesion, on dynamic load were analyzed. The main results from motion analyses and experiments were as follows;

(1) The direction of the normal force on the rim becomes downward when a circular wheel is operated on adhesive soil condition. This is caused by "contra-retractive adhesion".

(2) Newly designed rim sectional transducers installed on a circular wheel were used for experiments. The contra-retractive adhesion is measured by these transducers in the upward motion of the rim section on wet soil, and lift resistance is calculated from the adhesion with angle factors of the wheel.

(3) The lift resistance ratio on the rim is in the range of 0.07 to 0.10 in this study, and its influence is thought to be equivalent to that of the motion resistance.

(4) The superposition of the positive component of the vertical force shows that the reaction of the dynamic load becomes larger than the force measured by the axis transducer. The reaction of the increased dynamic load is named gross dynamic load and the force measured by the axis transducer is named net dynamic load.

(5) The increase of the dynamic load is caused by the transfer of the lift resistance to the rim contact area in the soil. This phenomena is named wheel internal load transfer.

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Table 1 Measured external forces acting on a wheel

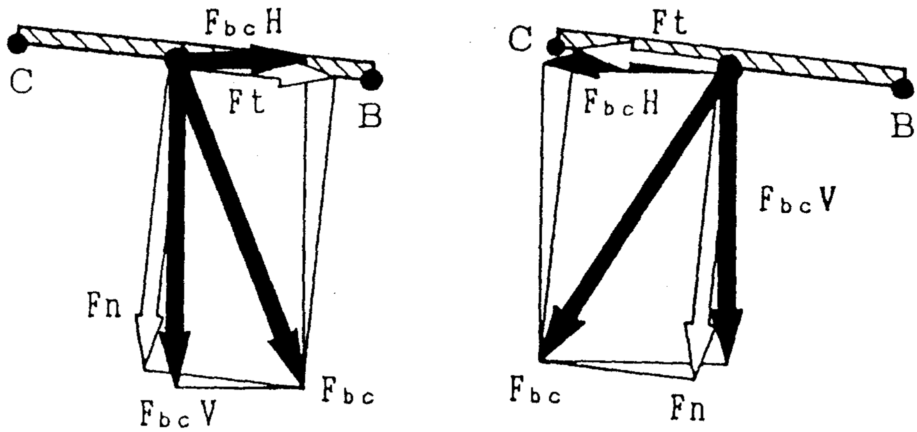
	Dry soil			Wet soil		
	M.R.(N)	D.L.(N)	M.R.R.	M.R.(N)	D.L.(N)	M.R.R.
L0	30.3	647.8	0.05	66.0	645.3	0.10
L1	43.2	792.2	0.06	94.0	796.3	0.12
L2	76.6	978.6	0.08	115.6	983.7	0.12
L3	88.9	1127.5	0.08	144.5	1137.0	0.13
L4	124.0	1297.0	0.10	198.1	1301.5	0.15

M.R. : Motion resistance D.L.: Dynamic load
M.R.R.: Motion resistance ratio

Table 2 Lift resistance ratio calculated from measured forces

	Max.(N)	Min.(N)	L.R.R.
L0	317.4	-25.6	0.08
L1	313.7	-31.5	0.10
L2	408.1	-35.7	0.09
L3	463.3	-30.6	0.07
L4	433.8	-30.0	0.07

L.R.R. : Lift resistance ratio



a. positive travel reduction

b. negative travel reduction

Fig. 1 Schematic diagram of external forces acting on a lug face

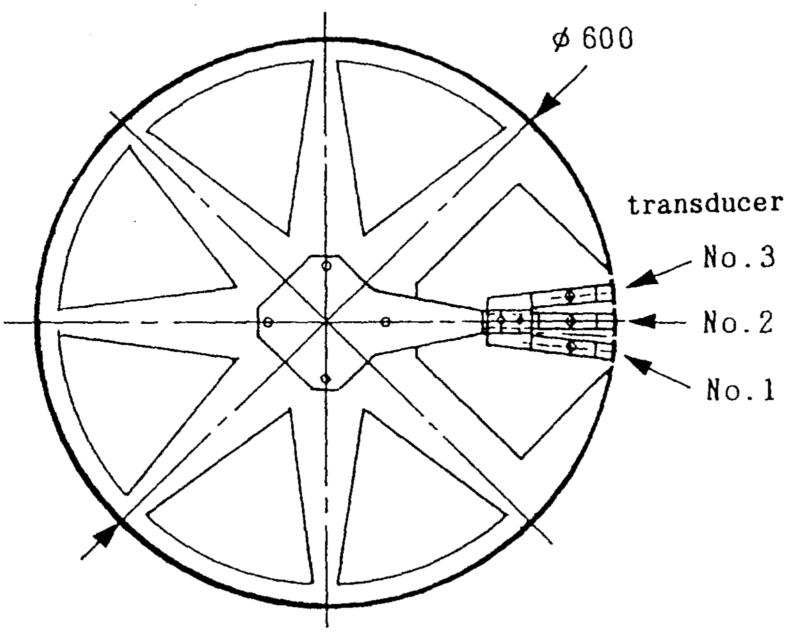


Fig. 2 Schematic view of rim sectional transducers installed to a tested wheel

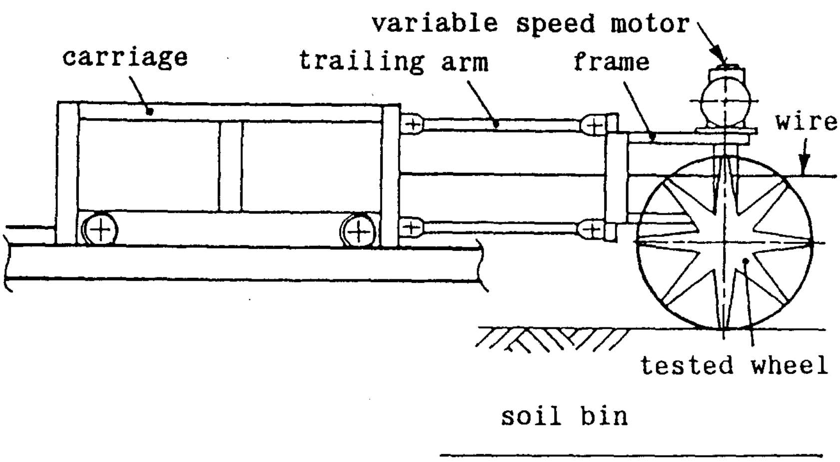
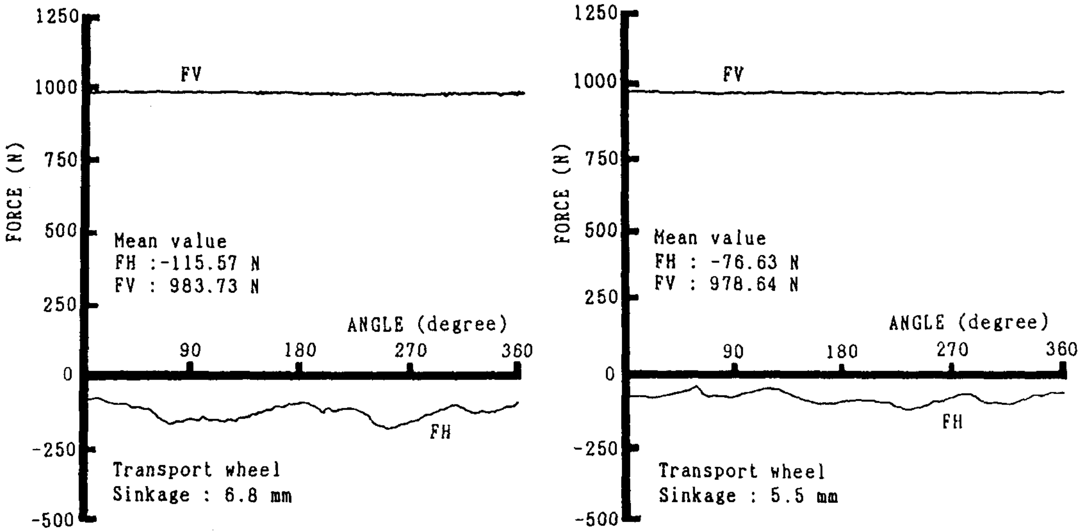
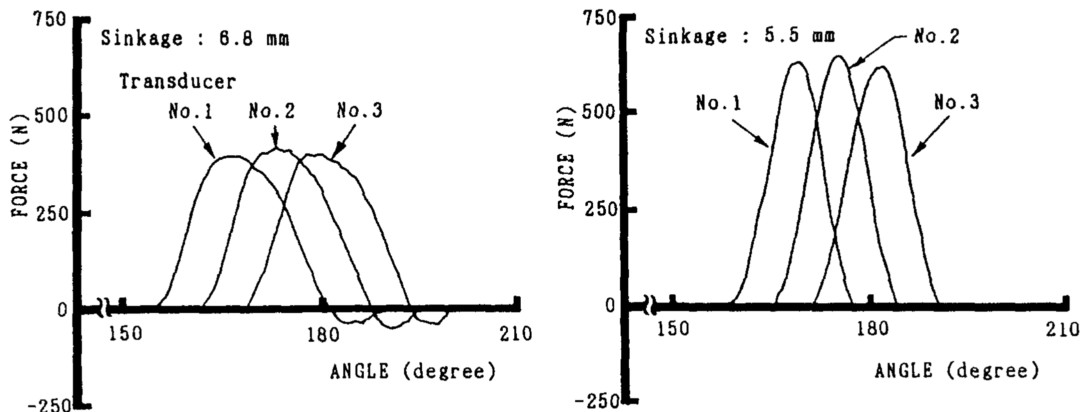


Fig. 3 Schematic view of a experimental apparatus



a. wet soil b. dry soil

Fig. 4 Examples of measured forces by an axis transducer



a. wet soil b. dry soil

Fig. 5 Examples of measured forces by rim transducers

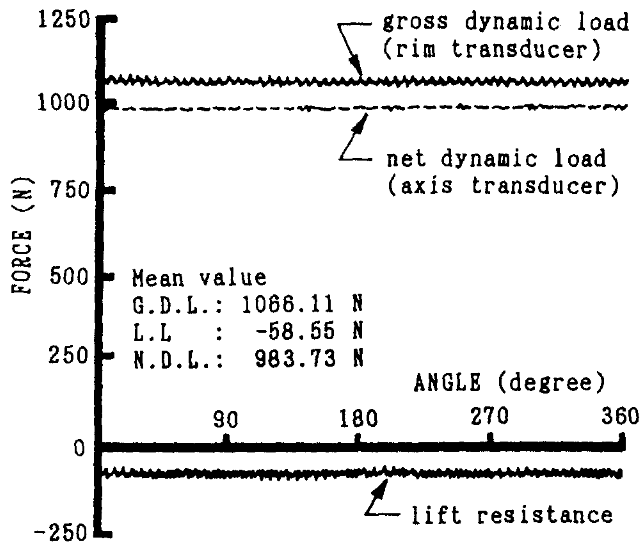


Fig. 6 Lift resistance and gross dynamic load calculated from forces measured by a rim transducer

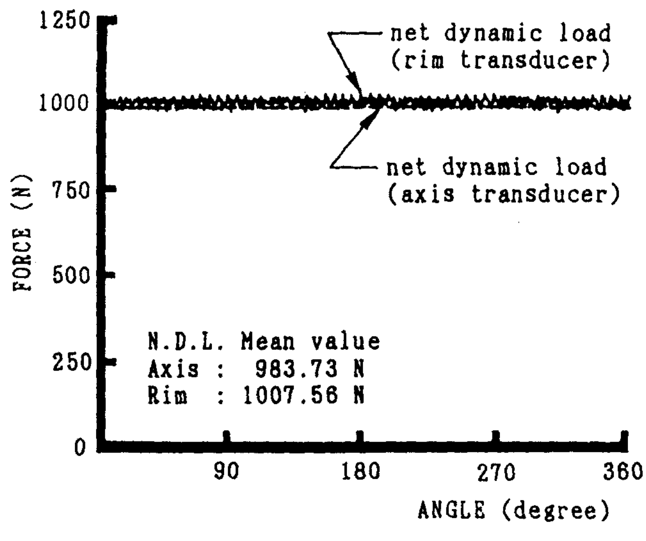


Fig. 7 Superposition of the lift resistance to the gross dynamic load