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ON FORCES ACTING ON TRACTOR THREE-POINT LINKAGE AND ROTARY TILLING SYSTEM

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ABSTRACT

The forces acting on tractor three-point linkage were analyzed including the rear cover action of a rotary tiller which is ignored usually. The relation of link force and tillage resistance is expressed as a linear form. The link forces vary with tilling torque from negative force to positive in the free-link, though in the fixed-link they increase without change of force sign. The effect of the rear cover resistance appeared in the link forces in the fixed-link.

Key Word : Three-point linkage, Rotary tiller, Tractor, Link force

INTRODUCTION

The forces acting on a three-point linkage and rotary tilling system differ from those during plowing operation. Usually, It is complicated because the thrust acts mainly on it.

To understand the characteristics of link force for the purpose of designing, the influences of the tilling conditions and the tilling resistance to the link forces were investigated including the effect of the rear cover resistance.

LINK FORCE

Link Force in Free-link Tilling

The resistance from tiller acts on the tractor body through the upper and lower link. Therefore, the link forces act as reacting force toward the tractor body and tiller.

The balance of external forces in the free three-point link and the rotary blades is simplified in Fig. 1. In this system, the link point A, B and hitch point C, D are connected by the pin. The mast CD and tiller member DE are rigid coupling. Therefore, the resultant force of the external force acting on tiller is transferred by the part CDE as the axial force on the upper and lower link.

The static relationship of the upper and lower forces for the resistance of tiller can be represented as follows. When the forces are divided into the vertical and horizontal components on the vertical projection plane in the direction of travel. Let the symbol of the tensile force in upper link and that of the compressive force in lower link be positive sign.

$$F_u\cos\alpha - F_l\cos\beta = \mu_G R_G - R\cos\theta + R_c\cos\gamma \tag{1}$$

$$F_u\sin\alpha - F_l\sin\beta = R\sin\theta - W_R + R_G + R_c\sin\gamma \tag{2}$$

where

F_u :upper link force

F_l :sum of the component of lower link in the projected plane perpendicular to the direction of travel

α, β :angle of inclination of upper link and lower link, respectively

R :reaction force of the soil on the blades

θ :tilling reaction force angle

W_R :weight of tiller

R_c :reaction force of the soil on the rear cover

γ :rear cover reaction force angle

and other symbols are shown in Fig. 1.

On the other hand, the relationship between the tilling reaction force and tilling torque can be represented as shown in equation (3), based according to the geometry relationship in Fig. 2.

$$R = \frac{T}{r\cos(\theta-\delta)} \tag{3}$$

where

T :tilling torque

The relation between the link force and tilling torque takes the form of a linear equation as:

$$F_u = K_u T + C_u \tag{4}$$

$$F_l = K_l T + C_l \tag{5}$$

where

$K_u = M_1 K \quad , \quad C_u = M_2 W_R + M_3 R_c$

$K_l = N_1 K \quad , \quad C_l = N_2 W_R + N_3 R_c$

$$K = \frac{1}{r\cos(\theta-\delta)}$$

$$M_1 = \frac{\sin(\theta+\beta)}{\sin(\alpha-\beta)} + \frac{(\cos\beta-\mu_G\sin\beta)\{(h-h_e+V_y)\cos\theta-(l_R-e-V_x)\sin\theta\}}{\sin(\alpha-\beta)\{\mu_G(V_y+h_G)-V_x+l_R+l_G-e_G\}}$$

$$M_2 = \frac{(\cos\beta-\mu_G\sin\beta)(l_R+l_e-V_x)}{\sin(\alpha-\beta)\{\mu_G(V_y+h_G)-V_x+l_R+l_G-e_G\}} - \frac{\cos\beta}{\sin(\alpha-\beta)}$$

$$M_3 = \frac{(\mu_G\sin\beta-\cos\beta)\{(J_x-V_x)\sin\gamma+(V_y-J_y)\cos\gamma\}}{\sin(\alpha-\beta)\{\mu_G(V_y+h_G)-V_x+l_R+l_G-e_G\}} + \frac{\sin(\gamma-\beta)}{\sin(\alpha-\beta)}$$

$$N_1 = \frac{\sin(\theta+\alpha)}{\sin(\alpha-\beta)} + \frac{(\cos\alpha-\mu_G\sin\alpha)\{(h-h_e+V_y)\cos\theta-(l_R-e-V_x)\sin\theta\}}{\sin(\alpha-\beta)\{\mu_G(V_y+h_G)-V_x+l_R+l_G-e_G\}}$$

$$N_2 = \frac{(\cos\alpha-\mu_G\sin\alpha)(l_R+l_e-V_x)}{\sin(\alpha-\beta)\{\mu_G(V_y+h_G)-V_x+l_R+l_G-e_G\}} - \frac{\cos\alpha}{\sin(\alpha-\beta)}$$

$$N_3 = \frac{(\mu_G\sin\alpha-\cos\alpha)\{(J_x-V_x)\sin\gamma+(V_y-J_y)\cos\gamma\}}{\sin(\alpha-\beta)\{\mu_G(V_y+h_G)-V_x+l_R+l_G-e_G\}} + \frac{\sin(\gamma-\alpha)}{\sin(\alpha-\beta)}$$

The symbols in coefficients are shown in Fig. 1.

Since α, β, γ and V_x, V_y, J_x, J_y, R_c are constants when the tilling depth is kept constant, the upper and lower link force may be represented in the form of a linear equation of tilling torque such as equations (4) and (5).

In general, the values of C_u, C_l become the negative values in equation (4) and (5), so that the upper link force is converted into a compressive force and the lower link force into tensile force when the tilling torque is small.

Link Force in Fixed-link Tilling

The balance of the external forces and the rotary blades on the fixed link is simplified as shown in Fig. 3.

Since hydraulic control changes with the change of the tilling depth, the tiller is supported by F_t (lift rod force).

The static relationship between the force of upper, lower and lift rod to the resistance of the tiller as shown in Fig. 3 can be expressed as follows.

$$F_u\cos\alpha+F\cos\zeta+F_t\cos\phi=-R\cos\theta+R_c\cos\gamma \tag{6}$$

$$F_u\sin\alpha+F\sin\zeta-F_t\sin\phi=R\sin\theta+R_c\sin\gamma-W_R \tag{7}$$

where symbols in the equations are shown in Fig. 3.

Deriving from equation (6), (7) and equation (3), the upper and lower link force can be represented by the linear equation of force for tilling torque as in equations (8) and (9).

$$F_u=K_uT+C_u \tag{8}$$

$$F_l=K_lT+C_l \tag{9}$$

where

$$K_u=\frac{A_2}{A_1}K \quad , \quad C_u=\frac{A_3}{A_1}W_R-\frac{A_4}{A_1}R_c,$$

$$K_l=(B_1A_6+B_4A_5)K \quad , \quad C_l=(B_2A_6+B_5A_5)W_R-(B_3A_6+B_6A_5)R_c$$

$$A_1=(D_x-C_x)\sin\alpha+(C_y-D_y)\cos\alpha \quad , \quad A_2=(D_y+h-h_e)\cos\theta-(l_R-e-D_x)\sin\theta$$

$$A_3=l_R+l_e-D_x \quad , \quad A_4=(J_x-D_x)\sin\gamma+(D_y-J_y)\cos\gamma$$

$$A_5=\sin\beta+\frac{D_x-B_x}{l_t}\tan^{-1}\phi \quad , \quad A_6=\cos\beta-\frac{D_y-B_y}{l_t}\tan^{-1}\phi$$

$$B_1=\cos\theta+\frac{A_2}{A_1}\cos\alpha \quad , \quad B_2=1+\frac{A_3}{A_1}\cos\alpha \quad , \quad B_3=\cos\gamma+\frac{A_4}{A_1}\cos\alpha,$$

$$B_4=\frac{A_2}{A_1}\sin\alpha-\sin\theta \quad , \quad B_5=1+\frac{A_3}{A_1}\sin\alpha \quad , \quad B_6=\sin\gamma+\frac{A_4}{A_1}\sin\alpha,$$

where

C_x, C_y, D_x, D_y :coordinates of the hitch point C and D, respectively

Other symbols in each of the coefficient are shown in Fig. 3.

MATERIALS AND METHODS

Tractor and Force Measurements

An experimental tractor with a rear drive system (nominal power 12.5 kW) and installed with a side drive rotary tiller, with the rotary blades (30) and tilling width of (1300 mm). The tiller is the standard equipment for the its tractor model with tail wheel, was used for this experiment. The length of the upper link is 205 mm, the length of the lower link (projection) is 625 mm.

Strain gages were fixed to the hollow shaft of the upper link. The sensitive octagonal ring was used for the lower link. By using the sensitive octagonal ring it was possible to ignore the effect of the bending moment on the lower link in the fixed link condition and to precisely only single force.

Strain gages were fixed on the rear cover directly to measure the force acting on the rear cover. The resistance force and the action point for rear cover can be evaluated through the value measured from the strain gage.

Field and Condition

The soil type belongs to the sandy soil, based on the triangular diagram classification.

The testing soil was processed in the following procedure:
The soil was pulverized and was adequately compacted to meet the experimental requirement. Soft and hard soil were dried under adequate moisture condition. The average moisture content and the average hardness index of the soil as determined using Yamanaka soil hardness tester are shown in Table 1.

Tilling depth was set at 12 cm, then the flat breaking was carried out. The tilling pitch target was set to be, 6.1, 8.8, 12.6cm respectively, however the actual result was slightly different from the target pitch.

RESULTS AND DISCUSSION

Link Force in Free-link Tilling

The upper and lower link forces change according to the resistance from the inertia and from soil to tiller resistance produced by the cutting action of tillage blade. Since the tiller axle torque is the major resistance of the soil acting on rotary blade, it affected the link force considerably. The example is shown in Fig. 4.

The fluctuation of lower link force is shown to alternate from the left and to the right link almost mutually.

To estimate the tilling reaction force from the tilling torque, it is necessary to know the tilling reaction force angle. The angle is given as $25° \sim 35°$ in ordinary clayey soil, but in the case of maximum tilling depth it is $30° \sim 40°$ (JSAM, 1984).

The relationship of the angle θ , the link force and the resistance of tiller can be represented as follows (Ikemi et al., 1987).

$$k=\frac{I}{T}[F_u\sin\alpha-F_l\sin\beta+F_t\{\frac{l-l_t}{l}\sin\phi\cos\beta-\sin(\phi-\beta)\}+W_R-R_c\sin\gamma]$$

$$\theta=\arctan\frac{k\cos\delta}{1-k\sin\delta}$$

The relationship between k and θ is shown in Fig. 5, where $h_e \fallingdotseq h/3$ and $r \fallingdotseq r'$ in Fig. 2. θ increases with an increase in k and decreases with an increase in R_c. θ may be changed by the depth of tilling. k value was in the range of 0.3~0.5 in this test. θ was obtained as 25°~30°.

When soil condition is changed from the soft soil into the hard soil, the relation between the tilling torque and the average force of the upper and lower link is shown in Fig. 6.

The lower link force F_l is the resultant of forces of the left and right link, the straight line is the calculated value from equations (4) and (5). Since the measured tilling depth is scattered the average tilling depth of 11 cm was chosen for the calculation. The necessary elements of the tractor is given in Table 2.

The absolute value of the force is small for softer soil, and the force is compressive force on upper link and tensile force on lower link. The absolute value of the force becomes large for hard soil and the direction of the force is reversed. The force is tensile on upper link and compressive on lower link.

There exist some effect of the rear cover force on the measured values of the force acting on the lower link. There are differences between the calculated values of the upper and lower link forces when the force acting on the rear cover is taking into consideration and when the rear cover force is ignored. The differences are shown in Fig. 6. The rear cover force has a decreasing effect on the lower link force. The influence of the rear cover force is more significant on the lower link force.

Link Force in Fixed-link Tilling

In the fixed-link(controlled-link) tillage, the upper link and the lower link are always subjected to the tensile and the compressive force respectively, regardless of tilling torque. This is in contrast to the result from the free-link tillage. Fig. 7 shows the case of rear cover force acting and when it is ignored.

Both the measured and the calculated force of the upper and lower link are larger when the rear cover force influence is taking into consideration as compared to when the rear cover force is totally ignored.

CONCLUSIONS

1. The mean force of the free and fixed-link can be represented in the form of a linear equation of the mean tilling torque.
2. With tilling torque increase, the force acting on the upper link is converted from the compressive force into the tensile force and the force acting on the lower link from the tensile force into the compressive force in the free-link condition.
3. In the fixed-link condition, the upper and the lower link are subjected to the tensile force and the compressive force respectively, regardless of tilling torque.
4. The effect of the rear cover force on the link system is more significant in the fixed-link system than in the free-link system.

REFERENCES

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Table 1. Soil conditions

		Moisture content%	Hardness kPa
Soft soil	a	18.7	500
	b	19.6	360
	c	20.0	255
Hard soil	a	17.0	762
	b	17.9	1160
	c	18.5	920

Table 2. Tractor and tiller elements

W_R	2000 N	l_E	0 mm
l_R	850 mm	h_G	110 mm
l_G	750 mm	h_e	36.7 mm
r	245 mm	μ_G	0.6

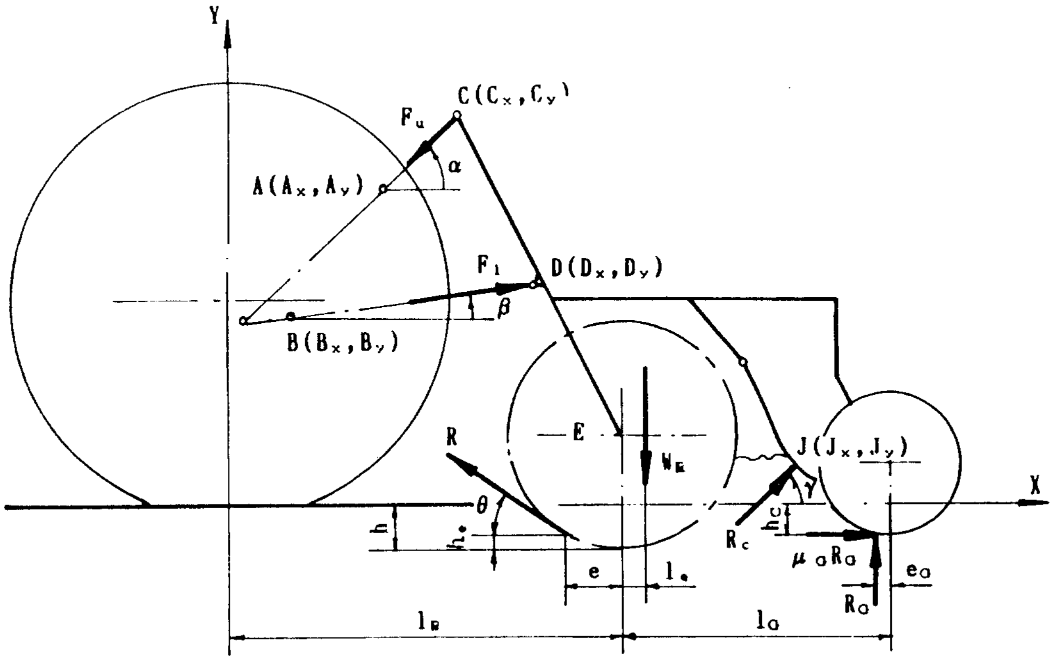

Fig. 1. Force diagram showing, forces acting on three-point linkage system in free-link.

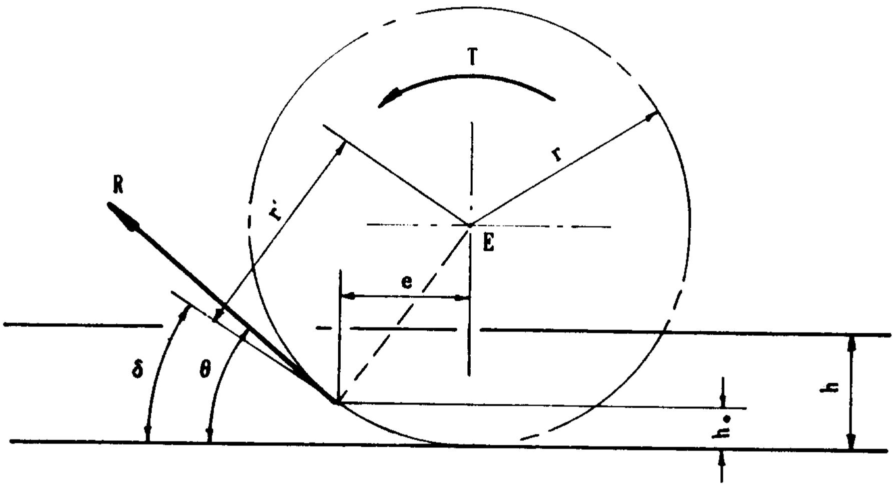

Fig. 2. Schematic diagram of tilling reaction force.

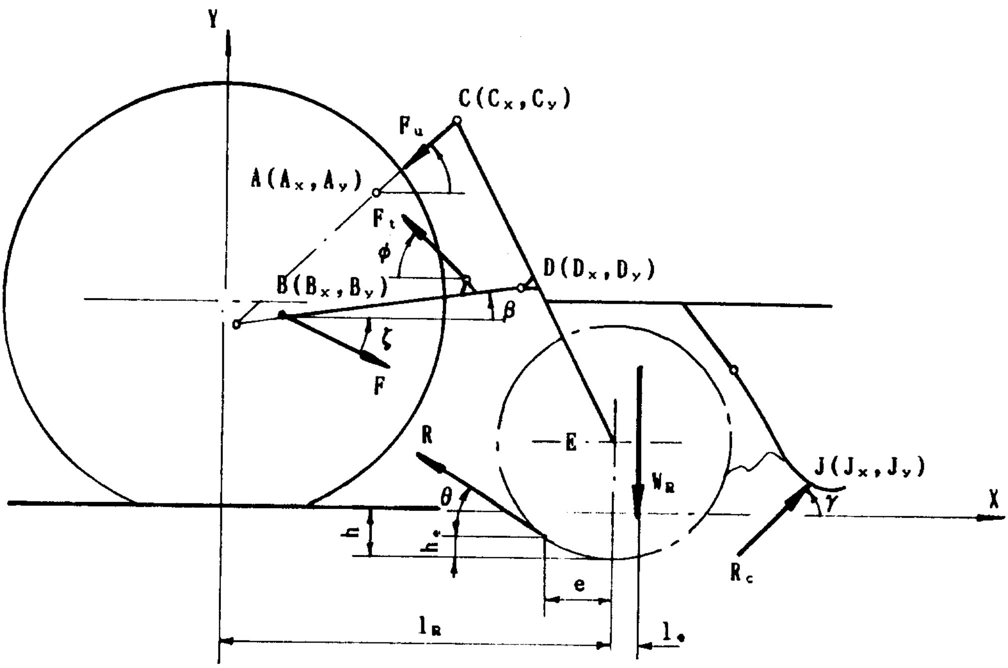

Fig. 3. Force diagram showing forces acting on three-point linkage system in fixed-link.

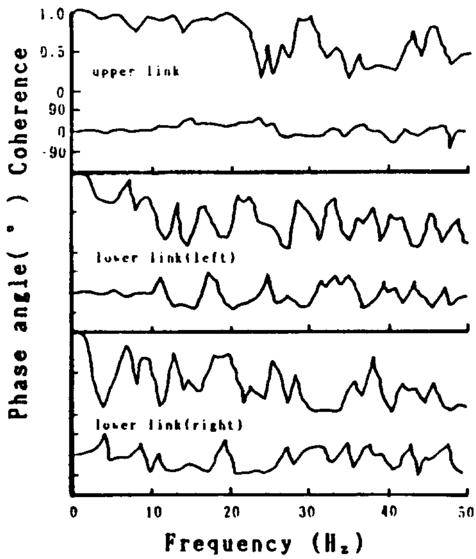

Fig. 4. Response of link acting force to tilling torque.

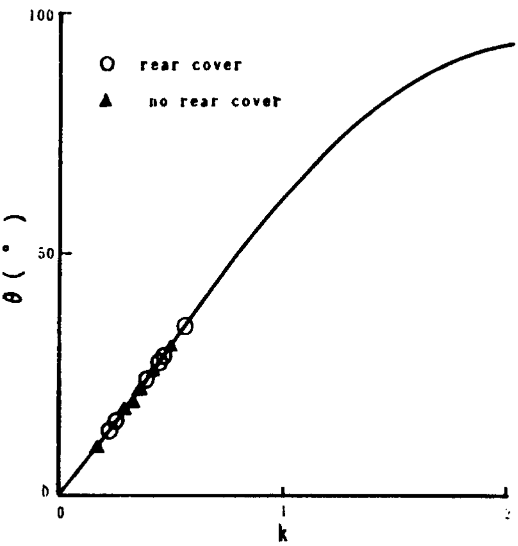

Fig. 5. Relationship between kand tilling reaction force angle.

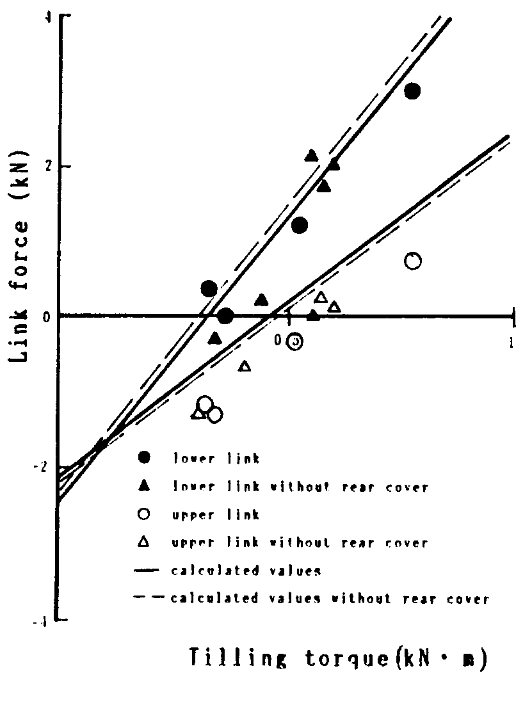

Fig. 6. Relationship between tilling torque and link forces in free-link.

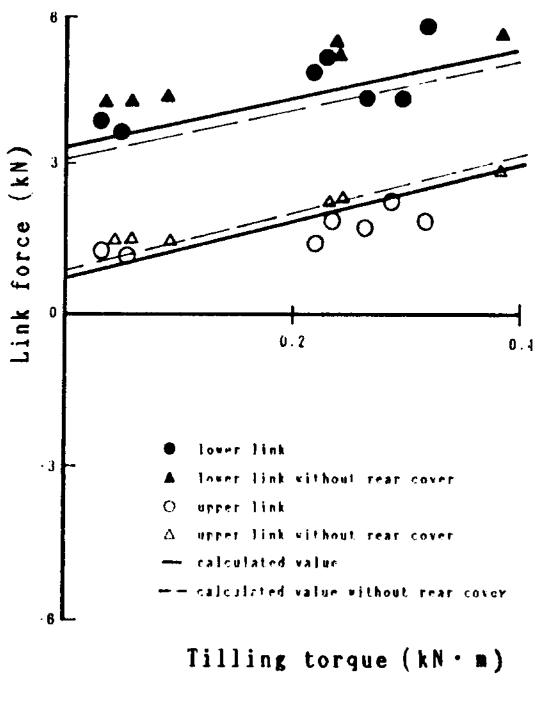

Fig. 7. Relationship between tilling torque and link forces in fixed-link.