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Studies on Design Theories of the Rubber Crawler for a Farm Machinery

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ABSTRACT

The authors propose in this research the equations to calculate the velocities, accelerations and penetration angles of the locus of lug motion for the rubber crawler mechanism.

In these equations with some values of factors, motion characteristics of all points or faces of the lug in the front-half of a rubber crawler. After that we also consider the reactionary force from the soil to the lug by computing the removed soil area for the purpose of understanding a relation between crawler lug and the soil in terms of estimating trafficability.

Key Word : Rubber crawler, Trafficability, Lug motion, Removed soil area

INTRODUCTION

The rubber crawler mechanism developed in Japan has been used for not only agricultural machinery but also for other machines. There are some good reasons for using for many machines.

The rubber crawler is lighter than the metallic one. It comes in handy and there should be many advantages. Nevertheless, a few research papers of the rubber crawler have been reported, because of a new mechanism developed in last only ten years.

To research the rubber crawler mechanism, we must comprehend not only

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characteristics of rubber crawler belt but also interactions between crawler belt and drive sprocket or other devices. So the authors proposed the equations of the lug motion loci. And we also considered the relation between lug and soil.

In this paper, we report more detailed relation between the lug and soil when the lug penetrate into the soil. And then, the thrust, motion resistance and buoyancy of the crawler mechanism are estimated from the removed soil area by lug.

THE EQUATIONS OF THE LUG MOTION LOCI

1. Factors and device details of rubber crawler mechanism.

The lug motion loci should be divided into several portions in order to analyze. In this paper, two of them are used for researching. The first portion is the straight moving portion E_1~E_2 as shown in Fig. 1. The second one is the circular portion from E_2~E_3.

Fig. 1 illustrates the detailed structures of front portion in the crawler mechanism on a flat surface;

O_D : center of drive sprocket

O_1 : center of first track roller

T : thickness of rubber crawler

L_V : vertical distance between O_D and O_1

L_H : horizontal distance between O_D and O_1

L_F : length of crawler between drive sprocket and the first track roller

R_P : at the location of steel codes center line of drive sprocket

r_1 : effective radius of the first track roller

V : circumference velocity of crawler along the drive sprocket

α: front-end inclination angle

H_L : lug height

w_B : lug-bottom length

w_T : lug-tip length

γ_1, γ_2: inclination angle of the side lug face

E_1 : the starting point of leaving the belt from the drive sprocket, on inside surface of crawler belt

E_2 : the contacting point with the first track roller on inside surface of crawler belt

E_3 : the point beneath the center of the first track roller, on inside surface of crawler belt

The crawler machine tend to incline, because the tail of the machine sink more deeply than the front. It is easy to simulate the motion loci of the lug with the machine inclination angle φ in all equations.

2. Velocities and acceleration on each point of lug.

The positional coordinates of the mid point of the lug's undertread face are denoted $C_L(X_{CL},Y_{CL})$ and the locus of this point is derived. The lug points A, B, C and D are defined by the position of C_L of the lug. Thus the change in the positions of A, B, C and D with respect to time can be derived from the locus of point C_L.

The equations of lug motion loci were differentiated by time and the authors have obtained new equations to calculate velocities and accelerations of the lug motion loci.

1) When the lug moves from drive sprocket to the first track roller, the values of velocities and accelerations on the points A, B, C and D are invariable.

In this situation, the equations of velocities and accelerations of the lug motion are as follows;

"C_L moves from E_1 to E_2."

$$\frac{dx}{dt} = V\left(1 - \frac{S}{100} - \cos\alpha\right) \tag{1}$$

$$\frac{dy}{dt} = -V\sin\alpha \tag{2}$$

$$\frac{d^2x}{dt^2} = \frac{d^2y}{dt^2} = 0 \tag{3}$$

2) When the lug moves along the first track roller, C_L moves from E_2 to E_3, the equations of velocities and accelerations on point A are as follows;

"Replace : $R_I = r_1 + t_1 + t_2$, $Q = \{(Vt - L_F)/(r_1 + t_1)\}$ "

$$\frac{dx_A}{dt} = V\left\{1 - \frac{S}{100} - \frac{R_I}{r_1 + t_1}\cos(\alpha - Q) + \frac{w_B}{2(r_1 + t_1)}\sin(\alpha - Q)\right\} \tag{4}$$

$$\frac{dy_A}{dt} = \frac{-V}{r_1 + t_1}\left\{R_l \sin(\alpha - Q) + \frac{w_B}{2}\cos(\alpha - Q)\right\} \tag{5}$$

$$\frac{d^2x_A}{dt^2} = \frac{-V^2}{(r_1 + t_1)^2}\left\{R_l \sin(\alpha - Q) + \frac{w_B}{2}\cos(\alpha - Q)\right\} \tag{6}$$

$$\frac{d^2y_A}{dt^2} = \frac{V^2}{(r_1 + t_1)^2}\left\{R_l \cos(\alpha - Q) - \frac{w_B}{2}\sin(\alpha - Q)\right\} \tag{7}$$

The equations for the other lug points, B, C, D, are obtained with the same method.

An example of lug motion locus is shown in Fig. 2. The examples of velocity and acceleration on all lug points, A, B, C, D, are also shown in Fig. 3~(a),(b).

As illustrated in Fig. 2, the lug motion locus draws a straight inclinational line when the lug moves from a drive sprocket to the first track roller. After that, the line transforms into trochoidal curve when the lug moves along the first track roller. In the latter situation, the direction of horizontal velocities on all points of the lug changes to negative from positive. Those velocities change in order of points C, B, D, A. The characteristics of lug faces are considered with these factors.

The tip face 'B~C' of the lug isn't a large factor for a thrust, because its horizontal velocity is very small.

The angle between the trailing lug side face 'A~B' and the plane surface is changed by a lug angle . So it is impossible to consider the motion resistance without lug angle γ. So we report the effect of trailing side face of lug in the later section of this paper.

The direction of horizontal velocity of the leading lug side face 'C~D' changes to negative as soon as the lug enters the curve section of locus. This face has an important factor to produce a thrust of the crawler mechanism.

The directions of vertical velocities on all the lug points are downward all the time. All faces press the soil to a downward direction. It seems to produce a buoyancy in all lug faces.

As illustrated in Fig. 3, the vertical velocities on the lug point C and D are positive at the end of the curve motion, because it is suggested that point C_L moves along the first track roller. Those vertical velocities approximate zero practically.

3. The area of removed soil by the lug faces.

The penetrating condition that the lug moves into the soil is fixed by lug's motive direction. The removed soil areas, ABB'A', BCC'B', CDD'C', in a second are obtained, when the lug moves from lug point ABCD to A'B'C'D'. Those areas are illustrated in Fig. 4. It seems that each lug face receives a reactionary force from the soil.

However, those areas may be changed by a relative positions between the lug and the soil surface. When the lug moves into the soil, those mean the areas in which the lug presses and removes the soil. The masses of the removed soil area are primary factors to decide the size of reactionary force which the lug receives. They are important factors to consider the not only positive but also negative thrust of the crawler mechanism. The removed soil areas by each face A~B, B~C and C~D of the lug are illustrated in Fig. 5. The removed soil areas are computed by means of changing the last three factors "S, α, γ". The results of calculating areas are illustrated in Fig. 6 (a)~(g). Standard parameters are as follows;

Circumference velocity of crawler : $V = 1000$mm/s,
Lug sinking depth : $H_L = 18$mm,
radius of the first track roller : $r_1 = 60$mm,
Crawler front-end inclination : $\alpha = 45$deg.,
Lug front or rear inclination : $\gamma = \gamma_1 = \gamma_2 = 25$deg.,
Travel reduction : $S = 0\%$.

1) The effect of travel reduction S. (See Fig. 6 ~ a,b,e)

As travel reduction is larger, the removed soil area becomes larger in leading side face of the lug. It concerns the thrust of the crawler mechanism.

In tip face of the lug, the effect of travel reduction is not so important to the thrust, because the removed soil area by lug tip face is much smaller than leading lug side face. However it is an important factor in point of a buoyancy by pressing the soil to a downward and a forward direction.

In A~B face, the value of the removed soil area is so small that the effect to the soil is very small.

2) The effect of crawler front-end inclination angle α. (See Fig. 6 ~ b,c,d)

As α value is larger, the removed area by the trailing lug side face becomes smaller when the lug moves straight. That area is almost zero, when the lug moves along the first track roller. As the removed soil area by the trailing lug side face is larger, the force against the thrust is bigger, because that face presses the soil to a forward direction and be received the reactionary force. So the value of the removed soil area by the trailing lug side face is a very important factor for the thrust of a rubber crawler.

As α value is larger, the removed area by the leading lug side face becomes larger obviously. This face presses the soil to a backward direction, so α value relates with the thrust in the leading lug side face. If α value is large, the removed soil area by tip lug face is slightly large , but the enlargement scale of removed area by tip lug face is smaller than the one by the leading lug side face.

3) The effect of lug front or rear inclination angle γ. (See Fig. 6 ~ b, f, g)

The removed soil area by the trailing lug side face is almost zero under the standard dimensions in this paper. The tip lug face doesn't relate with γ obviously. The removed soil area by the leading lug side face becomes larger with bigger γ. It seems that lug inclination effects to the thrust of the crawler mechanism.

CONCLUSIONS

The important factors for estimating trafficability of a rubber crawler mechanism are thrust, buoyancy and motion resistance. The motion characteristics of leading, trailing and tip lug faces of the rubber crawler are made clear through the simulation of the lug motion loci when the lug moves from drive sprocket to the place beneath the first track roller. Farther more, the characteristics of the thrusts, buoyancy and motion resistance are also obtained by computing the 2-dimensional areas of the soil removed by each lug face.

The results are as follows;

1) As shown in Fig. 3, the horizontal velocities of the point B and C are negative

against the machine driving direction. It is cleared that the tendency of the thrust produced by the tip lug face 'B~C' and leading lug side face 'C~D'. The tendency of the buoyancy is also cleared by the vertical downward velocities of the lug points.

2) As shown in Fig. 2 and Fig. 3, the absolute values of the accelerations on all lug points increase in a second when the motion loci of the lug shifts from straight to twist. The characteristics of the lug motion loci of the rubber crawler between the drive sprocket and the first track roller must be discriminated from that of the lug motion along the first track roller.

3) The 2-dimensional areas of the soil removed by that lug face are computed by the motion of the rubber crawler lug faces. It makes clear the characteristics of the reactionary forces which act on the rubber crawler lug from the soil .

4) These equations are useful for designing the rubber crawler lug in order to reduce the motion resistance and produce the thrust and buoyancy.

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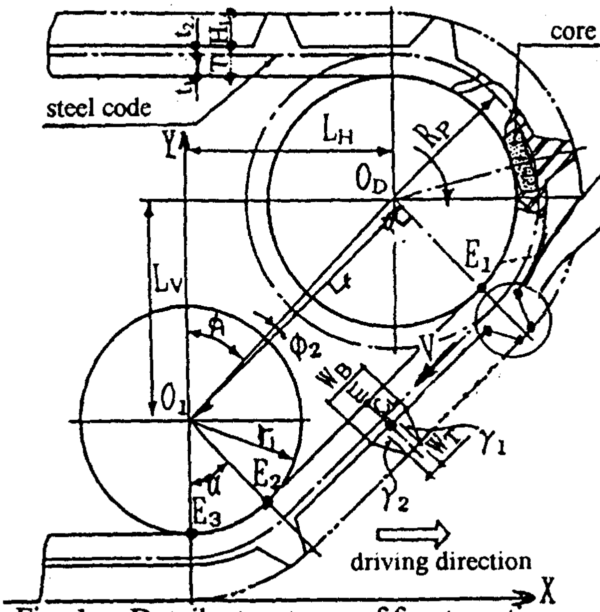


Fig. 1 Detail structures of front portion.

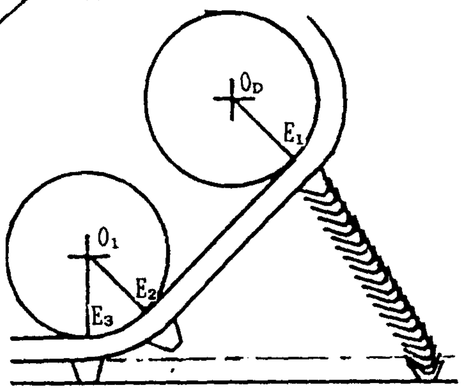
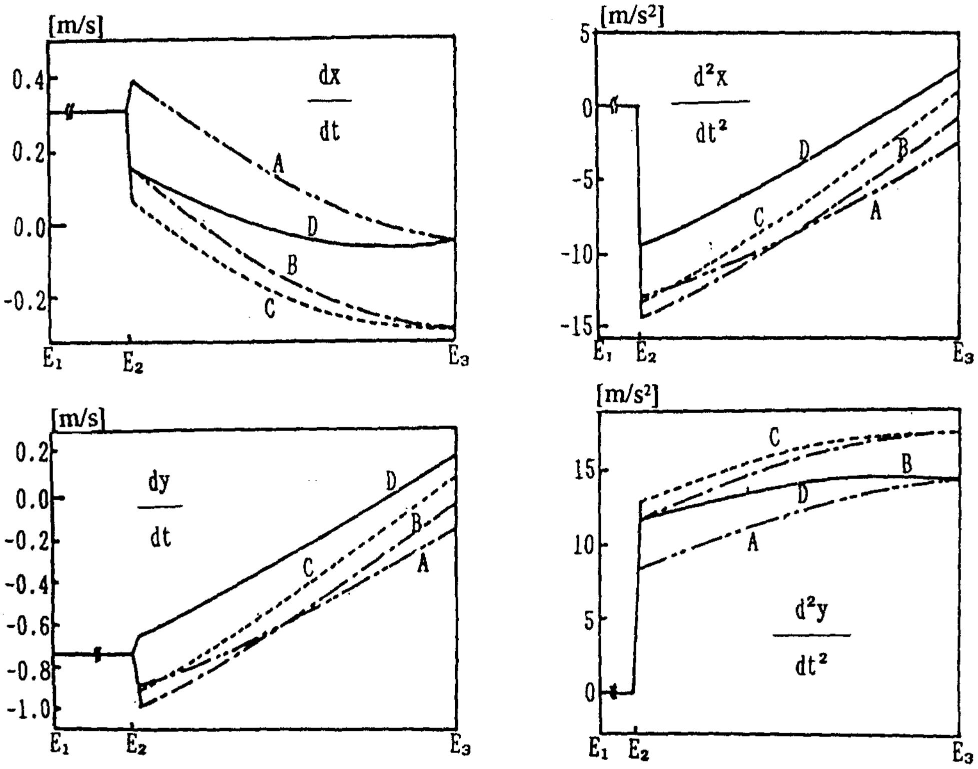


Fig. 2 Motion locus of a rubber crawler lug.



(a) Velocity

(b) Acceleration

Fig. 3 Changing velocity and acceleration on each lug point.

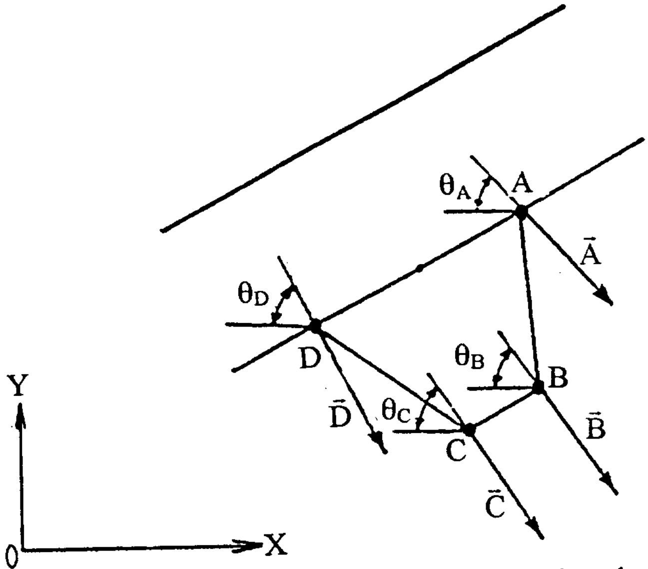
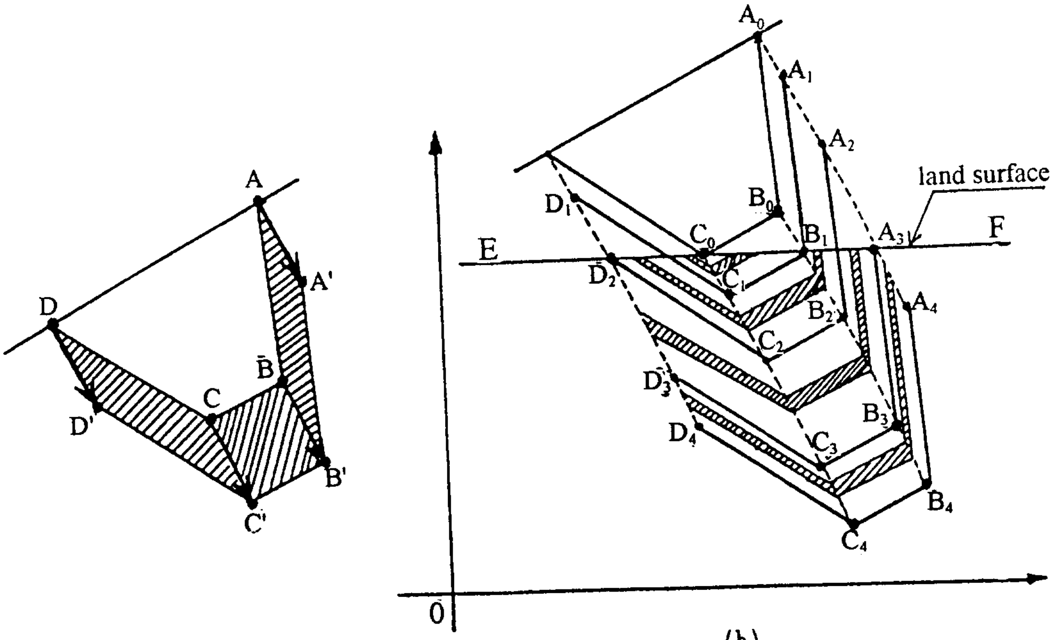
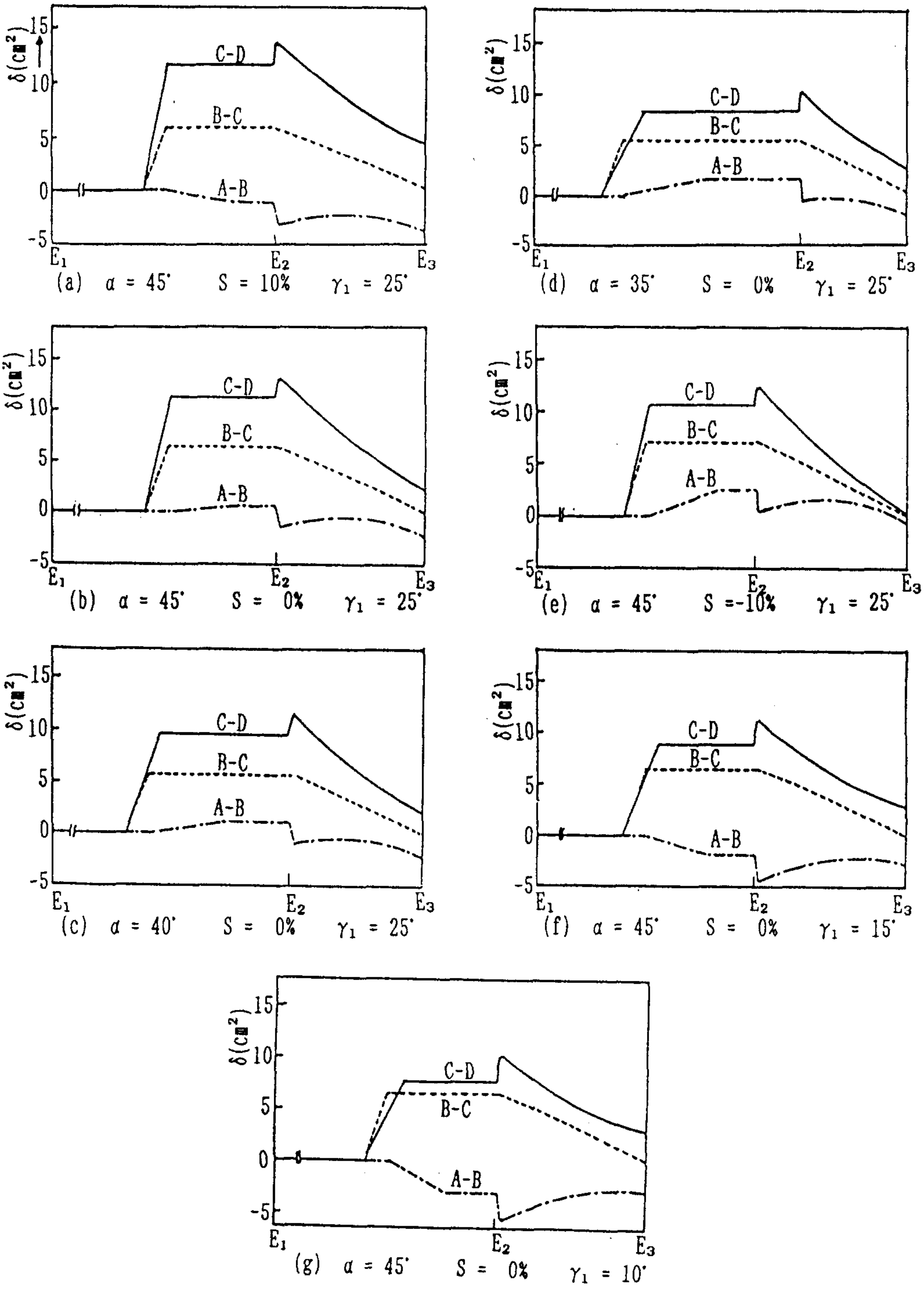


Fig. 4 Velocity vectors on points of a lug shape.



(a) (b)

Fig. 5 Schematic diagram of lug motion.



(a) α = 45° S = 10% γ_1 = 25°

(b) α = 45° S = 0% γ_1 = 25°

(c) α = 40° S = 0% γ_1 = 25°

(d) α = 35° S = 0% γ_1 = 25°

(e) α = 45° S =-10% γ_1 = 25°

(f) α = 45° S = 0% γ_1 = 15°

(g) α = 45° S = 0% γ_1 = 10°

Fig. 6 Removed soil area with each lug face.