ANALYTICAL SIMULATION OF TRAVEL RESISTANCE OF THE RUBBER CRAWLER SYSTEM FOR FARM MACHINERY

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ABSTRACT

The mechanism of the inner resistance in a rubber crawler system has been investigated to reduce the power requirement (Kitano et al. 1994). The rolling resistance of the track roller, which is one of the major inner resistances, was measured for seven different vertical loads. The rolling resistance changed periodically and could be classified into three types. In case of the vertical load less than 500N, the rolling resistance was almost constant. For the vertical load greater than 500N, the maximum value of the rolling resistance increased. Further more in case of the vertical load greater than 1200N, negative resistance appeared. Analytical simulation of the travel resistance based on experimental results and static equilibrium equations derived from three-dimension mechanical model for the rubber crawler system.

It was found that the simulation method was carried out to evaluate the travel resistance occurred by the rolling resistance of the track roller. The rolling resistance for each track roller arrangement and effects of the lug phase in the right and left rubber crawler could be estimated quantitatively.

Key Word : Rubber Crawler, Travel resistance, Inner resistance, Track Roller

INTRODUCTION

In Japan, the rubber crawler system is used for the harvesters, tractors and the other industrial machines. The advantages of the rubber crawler are due to lower weight than for the iron one, lower ground contact pressure and higher trafficability on the rough ground. The crawler system consumes more energy than for the wheel system, and has much vibration. Because of the rolling resistance of the rubber crawler belt and structure of the rubber crawler system. In this report, we measured the rolling resistance of the track roller driving on a rubber crawler in order to investigate the travel resistance caused by inner resistance on the horizontal rigid road. Analytical simulation of the travel resistance was conducted using experimental results and static equilibrium equations based on the three-dimension mechanical model of the rubber crawler system. The simulation results were applied to the measurement of power requirement of the crawler system under the different conditions of the track roller arrangement and the relative difference of the phase between left and right lug.

MEASUREMENT OF THE ROLLING RESISTANCE ON THE RUBBER CRAWLER

Fig. 1 shows contact state between parallel pattern crawler and track roller. The crawler belt for paddy field generally has higher lugs set in large pitch. Core bars are also attached to keep a tension of the crawler belt. Vertical spring constant of the rubber crawler is expressed by the periodical function which varies between lug's pitch. Deformation phenomenon of the rubber crawler due to loading of the track roller depends on lug, which would affect the rolling resistance of the track roller and travel resistance of the crawler system. We therefore measured the rolling resistances of the track roller driving on a rubber crawler (Inaba et al., 1997). The details are as follows.

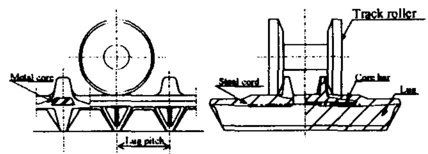

Fig.1 Contact state between parallel pattern crawler and track roller

Materials

Fig.2 shows the schematic diagram of a measuring the rolling resistance of the track roller driving on the rubber crawler belt. The track roller, which was dual rollers and its diameter was 120mm, was equipped with slide bearing to keep free against the vertical direction. The rubber crawler was fixed with its steel code in an iron case set on a roller conveyor. The oil cylinder was connected with the crawler case by iron rod and load cell to measure all horizontal force. Table 1 shows the weight conditions of this experiment.

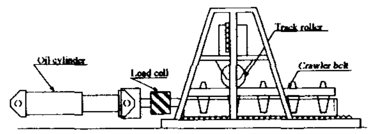

Fig.2 Schematic diagram of a measuring the rolling resistance

Table 1 Weight conditions

□	300N
[illegible]	490N
[illegible]	690N
[illegible]	890N
[illegible]	1080N
[illegible]	1280N
[illegible]	1470N

* including the weight of movement parts

Results

Fig.3,4,5 show examples of experimental results. These results were classified into three

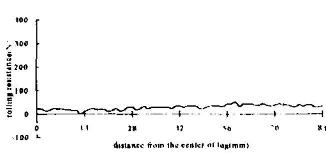

Fig.3 Rolling resistance of the track roller on the rubber crawler
(Track roller ϕ120mm, Weight condition No.1)

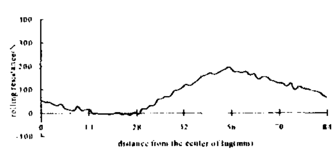

Fig.4 Rolling resistance of the track roller on the rubber crawler
(Track roller ϕ120mm, Weight condition No.4)

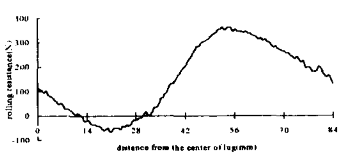

Fig.5 Rolling resistance of the track roller on the rubber crawler
(Track roller ϕ120mm, Weight condition No.7)

types of the characteristics. In case of the vertical load less than 500N, the rolling resistance was almost constant. For the vertical load greater than 500N, the maximum value of the rolling resistance increased. Furthermore in case of the vertical load greater than 1200N, negative resistance appeared. From these results, simulation of the travel resistance was performed.

SIMULATION OF THE TRVEL RESISTANCE FOR RUBBER CRAWLER SYSTEM

To calculate the travel resistance, static equilibrium equations based on the three-dimension mechanical model (See Fig.6) of the rubber crawler system (Inoue et al., 1990 Part1&Part2) was proposed. In this model, the spring constant of the rubber crawler is expressed by Fourier function $k(x)$ and pitching angle ϕ, rolling angle ψ, sinkage value q_i($_L$ or $_R$) of each track roller are expressed by following equations.

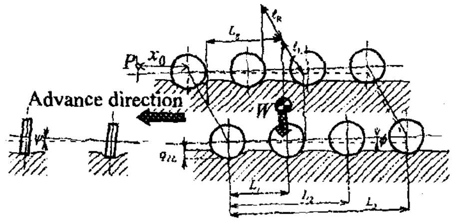

Fig.6 Mechanical model of the rubber crawler system

$$q_{iR} = q_1 - L_{i-1} \sin\phi \tag{1}$$

$$q_{1L} = q_{1R} + l\psi \tag{2}$$

$$x_i = x_0 + L_{i-1} \cos\phi \tag{3}$$

$$\phi = \frac{q_{1R}\sum_{i=1}^{n} k(x_i)_R + \sum_{i=1}^{n} f(x_i)_R - \frac{l_L}{l}W}{\sum_{i=1}^{n} k(x_i)_R L_{i-1}} \tag{4}$$

$$\begin{aligned}\psi = &\frac{1}{l\sum_{i=1}^{n} k(x_i)_L \sum_{i=1}^{n} k(x_i)_R L_{i-1}} \\ &\left\{\frac{W}{l}\left(l_R \sum_{i=1}^{n} k(x_i)_R L_{i-1} - l_L \sum_{i=1}^{n} k(x_i)_L L_{i-1}\right)\right. \\ &+ \sum_{i=1}^{n} f(x_i)_R \sum_{i=1}^{n} k(x_i)_L L_{i-1} - \sum_{i=1}^{n} f(x_i)_L \sum_{i=1}^{n} k(x_i)_R L_{i-1} \\ &\left. - q_{1R}\left(\sum_{i=1}^{n} k(x_i)_L \sum_{i=1}^{n} k(x_i)_R L_{i-1} - \sum_{i=1}^{n} k(x_i)_R \sum_{i=1}^{n} k(x_i)_L L_{i-1}\right)\right\}\end{aligned} \tag{5}$$

$$q_{1R}=\frac{\left\{W\left(x_0+L_g\right)-\sum_{i=1}^{n}\left(f(x_i)_R+f(x_i)_L\right)\left(x_0+L_{i-1}\right)\right\}\sum_{i=1}^{n}k(x_i)_L\sum_{i=1}^{n}k(x_i)_R L_{i-1}}{\sum_{i=1}^{n}k(x_i)_L\left\{\sum_{i=1}^{n}k(x_i)_R L_{i-1}\sum_{i=1}^{n}\left(k(x_i)_R+k(x_i)_L\right)\left(x_0+L_{i-1}\right)\right.}$$

$$\frac{-\sum_{i=1}^{n}k(x_i)_L\left(x_0+L_{i-1}\right)\left\{\frac{W}{l}\left(l_R\sum_{i=1}^{n}k(x_i)_R L_{i-1}\right.\right.}{\left.-\sum_{i=1}^{n}k(x_i)_R\sum_{i=1}^{n}\left(k(x_i)_R+k(x_i)_L\right)\left(x_0+L_{i-1}\right)L_{i-1}\right\}}$$

$$\frac{\left.-l_L\sum_{i=1}^{n}k(x_i)_L L_{i-1}\right)+\sum_{i=1}^{n}f(x_i)_R\sum_{i=1}^{n}k(x_i)_L L_{i-1}}{-\sum_{i=1}^{n}k(x_i)_L\left(x_0+L_{i-1}\right)}\frac{\left.-\sum_{i=1}^{n}f(x_i)_L\sum_{i=1}^{n}k(x_i)_R L_{i-1}\right\}+\left(\sum_{i=1}^{n}f(x_i)_R-\frac{l_L}{l}W\right)}{\left\{\sum_{i=1}^{n}k(x_i)_L\sum_{i=1}^{n}k(x_i)_R L_{i-1}\right.}$$

$$\frac{\sum_{i=1}^{n}k(x_i)_L\sum_{i=1}^{n}\left(k(x_i)_R+k(x_i)_L\right)\left(x_0+L_{i-1}\right)L_{i-1}}{\left.-\sum_{i=1}^{n}k(x_i)_R\sum_{i=1}^{n}k(x_i)_L L_{i-1}\right\}} \qquad (6)$$

W : Weight of the vehicle except crawler belt part contact to the ground

x_0 : Distance between arbitrary point P and the center of the first track roller

L_1, L_2, L_3 : Distance between first track roller and each track roller

L_g : Horizontal distance between the first track roller and the center of gravity

ϕ : pitching angle of the vehicle

q_1 : sinkage value of the track roller on the rubber crawler

l_0 : lug pitch of the rubber crawler

ψ : rolling angle of the vehicle

l_R : distance between the center line of the right track rollers and the center of gravity

l_L : distance between the center line of the left track rollers and the center of gravity

l : distance between center line of both track rollers

From these equations, the travel resistance was calculated by following method.

1. The vertical weight W_{i0} on each track roller is calculated from the results of the sinkage of the track roller and spring constant of the rubber crawler beneath the track roller center.
2. Two weight conditions W_k, W_{k+1} ($\because W_k < W_{i0} < W_{k+1}$) of rolling resistance of the track roller in experimental results(Inaba et al 1997) are selected.
3. The rolling resistances R_k, R_{k+1} are selected according to the weight conditions and the relative position between the track roller and lugs of the crawler belt.
4. Each rolling resistance $R_{iR(L)}$ is calculated from following Eq.(7) and add up as the

travel resistance.

$$R_{iR(L)} = \frac{W_{i0} - W_k}{W_{k+1} - W_k} \times (R_{k+1} - R_k) + R_k \tag{7}$$

5. The value of x_0 changes from 0 to 1 lug pitch (84mm) and recalculate the travel resistance.

EXPERIMENT

1.Materials

Fig.7 shows the schematic diagram of the measuring travel resistance. This device was made from the travel unit of a headfeeding combine. The tread of the travel unit was 690mm. Weight was 5250N. The position of center of gravity was 331mm from the first track roller center and 345mm from the center of the left crawler belt. An electric motor was used for power unit to reduce the effect of the vibration of power unit. Strain gages are attached on both drive shafts for measuring the torque and two photoelectric sensors were set in both sides. Reflect tapes were attached on every lug to measure the lug positions in travel. The vehicle had 4 track rollers (ϕ120mm) in each rubber crawler. They were the same type of the track roller used in former experiment (Inaba et al. 1997). The position of No.2 and No.3 track roller could be changed at the distance from No.1 to No.4 track roller to obtain the different travel characteristics. The width of crawler belt was 300mm, lug pitch was 84mm and its weight was 275N. They had parallel pattern lugs and they are also same type of the rubber crawler used in former experiment (Inaba et al. 1997). The tension of crawler belt was adjusted by the maximum space between track roller and inner surface of the crawler belt. It was 35mm.

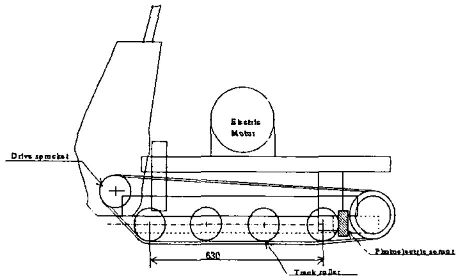

Fig.7 Schematic diagram of the experimental device

2.Method and Conditions

Experiment was performed on the concrete flat road in Kyushu University in March 2000. The velocity of vehicle was 0.04m/sec, which was minimum velocity of this vehicle, in order to reduce the dynamic phenomenon of vehicle. Three types of arrangements of track rollers (see Table 2) were tried

Table 2 The experimental conditions of track rollers arrangement

Arrangement	$1^{st} \sim 2^{nd}$ − $2^{nd} \sim 3^{rd}$ − $3^{rd} \sim 4^{th}$ (mm)
No.1	210−210−210
No.2	189−252−189
No.3	231−168−231

for three kinds of lug phases between left and right rubber crawler. Since it is difficult to adjust the lug phase exactly, the lug phase in travel was measured by the signals of photoelectric sensors. The r.m.s. value of tangential force(calculated by the torque) acting on a drive sprocket was introduced to compare with the same dimension of the travel resistances. The travel resistance was calculated under the same conditions of experiment.

RESULTS AND DISCUSSION

Fig.8 shows an example of the results of experiment for lug phase being 0. Fig.9 shows the result of simulation under the same conditions of experiment. There was a difference between experimental and simulation results because the resistance of other parts except track rollers might be included in the experimental result. The torque was measured when the vehicle drove in the air. Furthermore, as this resistance is supposed to include the weight of crawler belt contacted with the ground, we assume half of this resistance in experimental results was removed. (This idea needs more examinations.) Fig.10 shows r.m.s. values of the experimental results under the different conditions of lug phase and Fig.11 shows the simulation results of arrangement No.3. From those results, it was found that this simulation method was applicable to predict travel resistance caused by the rolling resistance of the track roller.

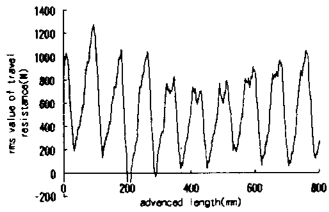

Fig.8 Experimental result of travel resistance on No.3 condition arragement of track rollers

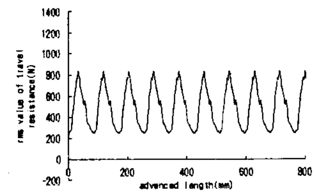

Fig 9 Simulate result of travel resistance on No 3 condition arrangement of track rollers

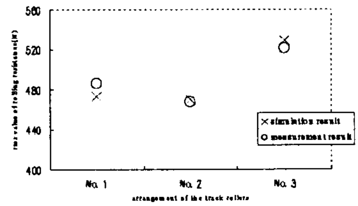

Fig.10 The comparison between experimental and simulation results of the travel resistances with arrangement of the track rollers

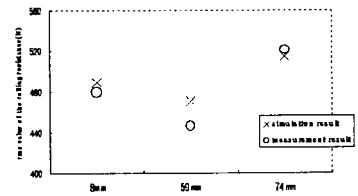

Fig.11 The comparison between experimental and simulation results of the travel resistances with the condition of difference of lug position (No.3 condition arragement of track rollers)

CONCLUSIONS

Analytical simulation of the travel resistance was carried out using experimental results and static equilibrium equations based on the three-dimension mechanical model of the rubber crawler system. As a result, it was found that this simulation method was applicable to predict travel resistance caused by the rolling resistance of the track roller. The rolling resistance against each track roller arrangement could be estimated quantitatively and we could evaluate the effects in the right and left difference of relative positions between the rubber crawler and the track roller. We thought that this theory has an important factor for design of arrangement of track rollers to reduce the travel resistance and also reduce the power requirement of the rubber crawler system.

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