IDENTIFICATINO OF DYNAMIC PARAMETER OF THE RUBBER CRAVLES SYSTEM FOR FARM MACHINERY

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ABSTRACT

The rubber crawler system for farm machine is composed of driving units such as track rollers, driving sprockets and rubber crawlers. Vibration characteristics of the rubber crawler system varies by driving speed, center of gravity, mass moment of inertia location arrangement of track rollers and dynamic parameters such as dynamic spring constant (k) and viscous damping coefficient (c) of a rubber crawler. In general, vibration of the rubber crawler system occurs by reason for mechanical interaction between the rubber crawler and track rollers. Because the dynamic spring constant and viscous damping coefficient vary periodically by mechanical characteristics(deformation characteristics) of the rubber crawler when track rollers drive on the between lugs of the rubber crawler. Therefore, both dynamic parameters k and c were expressed as Fourier series by authors through the shaking test of the rubber crawler and further, vibration characteristics of the rubber crawler system could be simulated analytically. However, actual values of dynamic parameters k and c are different from those obtained by the shaking test because dynamic characteristics of the rubber crawler vary by the effect of variable tension and driving resistance of track rollers. So, actual values of k and c should be identified in the condition of actual driving test.

In this study, dynamic parameters such as k and c of the rubber crawler system, which are expressed as Fourier series, were identified using the Gauss-Newton Method. Therefore, validity of identified parameters k and c was discussed through the simulation using experimental data of actual driving test. As a result, in the Fourier series of dynamic parameters of spring constant k and viscous damping coefficient c, excellent parameter convergence and simulation were observed using the Fourier series' zero order and first term of the dynamic model. Furthermore, it was clarified that identification for model parameters which are fitted to actual dynamic motion (vibration) wave of the crawler system was possible by using the time series data observed in vertical and pitching motion of the crawler system.

Key Word: Rubber crawler, Vibration characteristics, Simulation, Identification of Dynamic Parameters, Dynamic model, Gauss-Newton Method

INTRODUCTION

Vibration of the rubber crawler system occurs by reason for mechanical characteristics between the rubber crawler and track rollers; that is, track rollers drive on the rubber crawler with variable dynamic spring constant (k) and viscous damping coefficient (c).

In former study, k and c have been expressed as Fourier series, and also dynamic driving characteristics have been able to be simulated approximately from the dynamic model using these dynamic parameters by "INOUE et al. (1990)". From these results, if vibration characteristics could be presumed by using this dynamic model of the rubber crawler system for farm machinery, practical parameters k and c of the rubber crawler system expressed as Fourier series may be identified from data of actual driving test. Therefore in this study, at first, the authors simulated vibration characteristics using motion equations based on dynamic model, and then identified parameters k and c from data of actual driving test by Gauss-Newton Method in order to compare with driving simulation before identification "MINAMI (1994)".

DYNAMIC SPRING CONSTANT AND VISCOUS DAMPING COEFFICIENT

When track rollers drive on the rubber crawler, k and c vary periodically between core bars. So these parameters were given from the data of shaking test of rubber crawler, which could make periodical vibration.

Then k and c are expressed as the following Fourier series "H.F.Culb (1998)".

f : frequency of crawler lug[Hz]
N : a number of fourier factor
j : count variable of fourier factor
A_j, B_j, C_j, D_j : fourier factor
t : time[s]
α : phase angle of lug[rad]

$$k(t)=\frac{A_0}{2}+\sum_{j=1}^{N/2-1}\left(A_j\cos(2\pi ftj+\alpha)+B_j\sin(2\pi ftj+\alpha)\right)+\frac{A_{N/2}}{2}\cos\frac{N}{2}(2\pi ft+\alpha) \tag{1}$$

$$c(t)=\frac{C_0}{2}+\sum_{j=1}^{N/2-1}\left(C_j\cos(2\pi ftj+\alpha)+D_j\sin(2\pi ftj+\alpha)\right) \qquad (2)$$
$$+\frac{C_{N/2}}{2}\cos\frac{N}{2}(2\pi ft+\alpha)$$

DYNAMIC MODEL OF THE RUBBER CRAWLER SYSTEM FOR FARM MACHINERY

Dynamic three-dimensional model of the rubber crawler vehicle driving on a horizontal solid surface was proposed by "INOUE et al. (1990)", and its motion equations with dynamic parameters k and c were obtained in order to estimate the driving characteristics caused by mechanical interaction between the rubber crawler and track rollers.

On the other hand, in case of same lug phase between right and left crawlers, dynamic two-dimensional model is shown in Fig. 1, and then motion equations about vertical and pitching direction of the crawler system are obtained as follows. These differential equations were solved by the Runge-Kutta method.

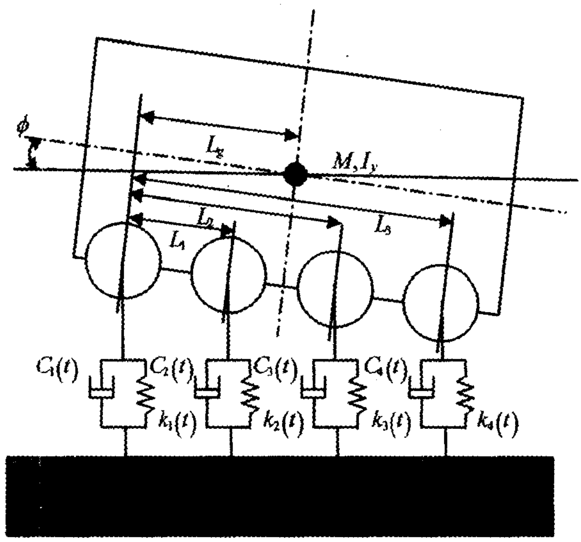


Fig. 1 Dynamic two-dimensional model

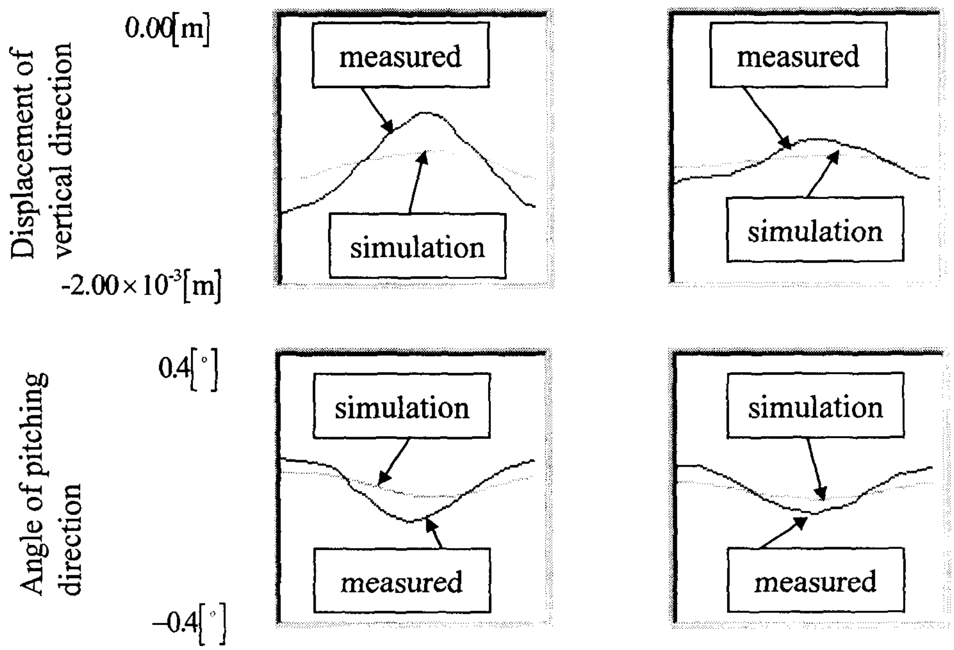
M : mass of the rubber crawler vehicle[Kg]
Z : displacement of vertical direction[m]
ϕ : angle of pitching direction[rad]
I_y : pitching moment of inertia[Kgm^2]
l : horizontal longitudinal distance from the center of gravity to each truck roller center[m]
t : time[s]
i : count variable of track roller number
"•": the derivative with respect to time

$$M\ddot{z}+2\left\{z\sum_{i=1}^{4}k_i(t)+\phi\sum_{i=1}^{4}k_i(t)l_i+\dot{z}\sum_{i=1}^{4}c_i(t)+\dot{\phi}\sum_{i=1}^{4}c_i(t)l_i\right\} = Mg \quad (3)$$

$$I_y\ddot{\phi}+2\left\{\phi\sum_{i=1}^{4}k_i(t)l_i^2+z\sum_{i=1}^{4}k_i(t)l_i+\dot{\phi}\sum_{i=1}^{4}C_i(t)l_i^2+\dot{z}\sum_{i=1}^{4}C_i(t)l_i\right\} = 0 \quad (4)$$

COMPARISON AND DISCUSSIONS BETWEEN EXPERIMENTAL RESULT AND THEORETICAL ANALYSIS

Comparison of experimental results and simulation about vertical and pitching direction of vehicle are shown in Fig. 2. Though there is a little error in comparison, the simulated values in case of each arrangement (arrangement 2,3) of the track rollers coincide with experimental result comparatively.



(track roller arrangement 2) (track roller arrangement 3)

Fig. 2 Comparison of vibration wave between simulation and measured

THEORY OF IDENTIFICATION OF DYNAMIC PARAMETERS

The parameters k and c varying periodically between lugs of a rubber crawler were expressed as Fourier series, and dynamic vibration characteristics and behavior of the rubber crawler system were able to presume. So, if vibration characteristics could be presumed approximately by using this dynamic model, practical parameters k and c of the rubber crawler system may be identified from data of actual driving test. For identification of Dynamic Parameters, Gauss-Newton Method, which is famous quasilinearization is used. This identification method makes it possible to identify the parameters by decreasing the error between the data of measurement and data of simulation model output corresponding to the same input data. When the data of the simulation model is equivalent to that of measurement exactly, the parameters are already identified. The correction value can be calculated by the following equation.

m: a number of correction

$\mathbf{p}^m$: parameter vector of the simulation model

$\mathbf{h}$: output vector of simulation model

$\mathbf{y}$: output vector obtained from the experiment

T_s: period for the updating of the parameter estimates

$$\mathbf{p}^{m+1} = \mathbf{p}^m + \left[\int_t^{t+T_s} \left[\frac{\partial \mathbf{h}(\mathbf{p}^m)}{\partial \mathbf{p}}\right]^{\mathrm{T}} \left[\frac{\partial \mathbf{h}(\mathbf{p}^m)}{\partial \mathbf{p}}\right] dt\right]^{-1} \times \left[\int_t^{t+T_s} \left[\frac{\partial \mathbf{h}(\mathbf{p}^m)}{\partial \mathbf{p}}\right]^{\mathrm{T}} \left[\mathbf{y} - \mathbf{h}(\mathbf{p}^m) dt\right]\right] \tag{5}$$

DISCOUSSIONS OF IDENTIFICATION ACCURACY

Equation of evaluation

The error sum of squares between analytical simulation and measurement about vertical and pitching direction is expressed as following equation (6) "NOGUCHI et al. (1993,1997)".

$S(p)$: error sum of squares between simulated and measured values

W_{y1}: weight variable of vertical displacement

W_{y3}: weight variable of pitching displacement

y_1: vertical displacement of measurement

y_3: pitching displacement of measurement

r : count variable of fourier factor

h_1 : vertical displacement of simulation
h_3 : pitching displacement of simulation

$$S(p)=\sum_{r=1}^{25}\left\{W_{y1}^{2}\left[y_1\left(t_0+\frac{r}{25}T\right)-h_1\left(t_0+\frac{r}{25}T\right)\right]^2 +W_{y3}^{2}\left[y_3\left(t_0+\frac{r}{25}T\right)-h_3\left(t_0+\frac{r}{25}T\right)\right]^2\right\} \tag{6}$$

The evaluation equation of identification accuracy is expressed as follows.

S_{ac} : evaluation value of identification accuracy [%]
S_{before} : error between simulated and measured values before identification
S_{after} : error between simulated and measured values after identification
n : a number of one side track roller

$$S_{ac}=\frac{\sqrt{\frac{S_{before}}{n}}-\sqrt{\frac{S_{after}}{n}}}{\sqrt{\frac{S_{before}}{n}}}\times 100 \tag{7}$$

Identification is performed by the calculation of data during one period of vertical and pitching displacement values. Then each displacement values calculated are expressed as continuous wave during one period. On the other hand, parameters k and c identified must be constant against the same rubber crawler system even if the arrangement of the track rollers is different. Therefore, parameters identified for each arrangement of the track rollers need to be averaged in order to decrease the error of parameters due to the difference of the arrangement of the track rollers. Finally, evaluation values using averaged values are shown in table 1. Further, comparison between vibration wave of measurement and identification using averaged values is shown in Fig.3.

Table 1 Results of identification

	S_{before}	S_{after} (average)	S_{ac} % (average)
Arrangement 1	2.6396×10^{-4}	2.0431×10^{-4}	12.02
Arrangement 2	9.8951×10^{-6}	6.8701×10^{-6}	16.68
Arrangement 3	2.3803×10^{-6}	1.7988×10^{-6}	13.07
Arrangement 4	4.6752×10^{-6}	3.0296×10^{-6}	19.50

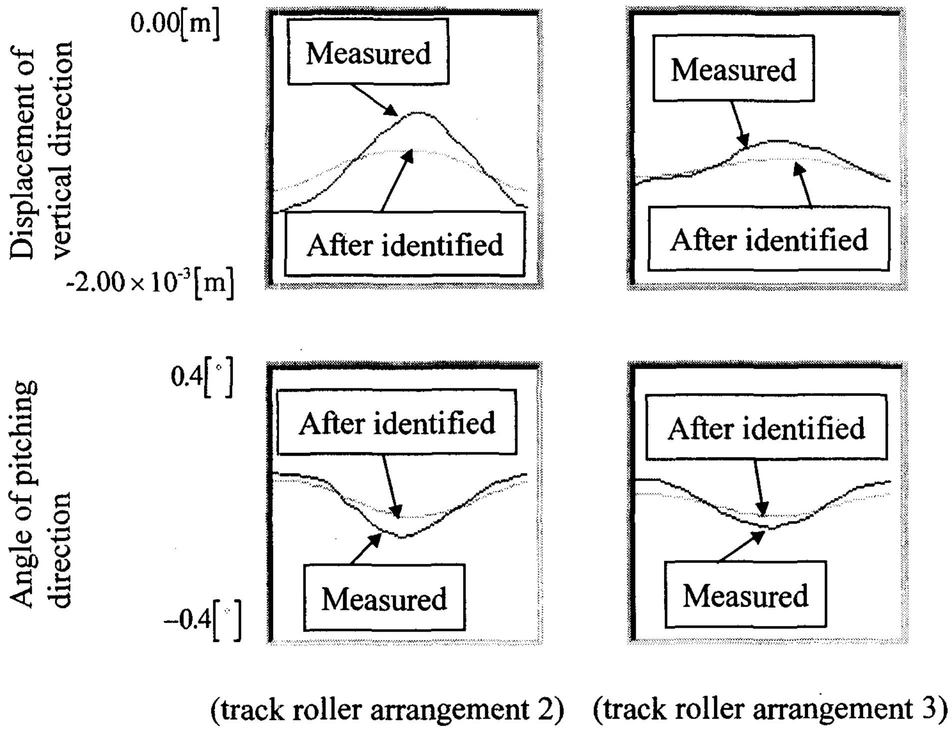


Fig.3 comparison of vibration wave between measured and identified

Results of identification and discussion

Each averaged parameters identified was obtained as follows.

A_0=1.861×10^6 A_1=12.7167×10^4 B_1=-1.7563×10^4 C_0=1.4769×10^4
C1=-0.0331×10^4 D1=-0.1726×10^4

Further, evaluation values of identification accuracy about four type arrangements of the track rollers are obtained as follows.

No.1: 12.02% No.2: 16.68% No.3: 13.07% No.4: 19.50%

All value were plus sign, so it was clarified that identification of model parameters, which were fitted to actual dynamic motion wave of the crawler system, was possible.

CONCLUSIONS

In this study, vibration characteristics of the rubber crawler system was simulated using basic motion equations based on the dynamic model, and then dynamic parameters k and c identified from data of actual driving test by Gauss-Newton Method were estimated through the comparison with simulation before identification.

As a result, the following conclusions were obtained:

(1) Identification using repeating data during constant period was available for decreasing influence of noise involved in measured data and improvement of identification accuracy.

(2) In the Fourier series of k and c, excellent parameter convergence and simulation were observed using Fourier series' zero order and first term of the dynamic model.

(3) As a result of identification using method of this study, evaluation values of identification accuracy about four type arrangements of the track rollers were, No1: 12.02%, No2: 16.68%, No3: 13.07%, No4: 19.50% respectively, so it was clarified that identification for model parameters which were fitted to actual dynamic motion wave of the crawler system was possible

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