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THE DRIVING THEORY OF THE COMBINE-HARVESTER FOR GATHERING FLAX

Volodymyr Bulgakov

National Agrarian University
Gueroyiv Oborony Str. 15, Kyiv, 252041, Ukraine, e-mail: mechanics@nauu.kiev.ua

Summary. Picking device oscillating motion in flax harvesting assembly is studied. Equivalent dynamic models of mechanical system with one and two degrees of freedom are developed.

Key words: combine harvester, flax, oscillating motion, dynamic models

INTRODUCTION

Let's study only vertical reciprocating (jumping) oscillating motion.

Then equivalent dynamic model will look like that depicted in Fig. 1. It is a mechanical system with one degree of freedom. Vertical displacement Z of sprung mass over rear wheels (there are no front ones) is accepted as generalized co-ordinate. The generalized co-ordinate will be calculated from the position of the static system equilibrium. Then motion of the given mechanic system is described by II-d mode Lagranghe equation [Horbovyi, Huskov *et al.* 1988]

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{z}}\right) - \frac{\partial T}{\partial z} = Q_z, \tag{1}$$

where:

$$T = \frac{1}{2} m\dot{z}^2,$$

$$P = \frac{1}{2} C(z-h),$$

$$h = h(t),$$

$$\Phi = \frac{1}{2}\mu(\dot{z}-\dot{h})^2,$$

where:

$m = \dfrac{Ml}{\ell}$ – mass of the combine-harvester's part performing rotary oscillation.

$$Q_z = Q_z^{(P)} + Q_z^{(F)} + Q_z^{(Fr)},$$

$$Q_z^{(P)} = -\frac{\partial P}{\partial z} = -c(z-h),$$

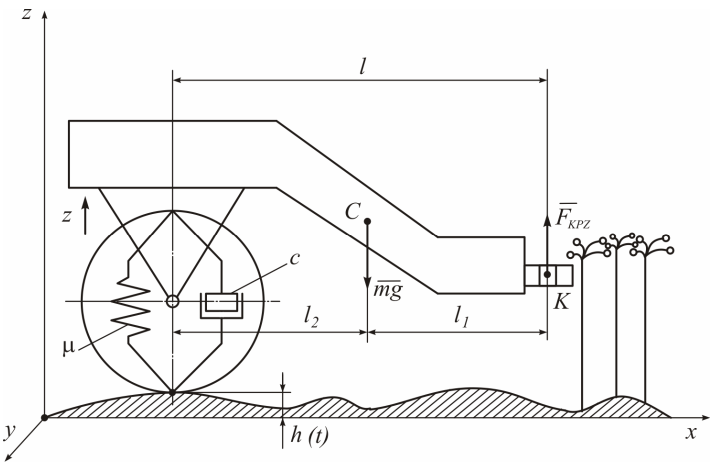

Fig. 1. Oscillation mechanical system with degree of freedom

$$Q_z^{(F)} = -\frac{\partial F}{\partial \dot{z}} = -\mu(\dot{z} - \dot{h}), \tag{2}$$

$$Q_z^{(Fr)} = 0,$$

$$Q_z = -c(z-h) - \mu(\dot{z} - \dot{h}),$$

$$\frac{\partial T}{\partial \dot{z}} = m\dot{z},$$

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{z}}\right) = m\ddot{z},$$

$$\frac{\partial T}{\partial z} = 0,$$

Substituting (2) in (1), we obtain

$$m\ddot{z} = -c(z-h) - \mu(\dot{z} - \dot{h}),$$

$$\ddot{z} = -\frac{c}{m}(z-h) - \frac{\mu}{m}(\dot{z}-\dot{h}),$$

$$\ddot{z} + \frac{\mu}{m}\dot{z} + \frac{c}{m}z = \frac{ch}{m} + \frac{\mu}{m}\dot{h}, \tag{3}$$

Let

$$\frac{c}{m} = k^2,$$
$$\frac{\mu}{2m} = n,$$

Then

$$\ddot{z} + 2n\dot{z} + k^2 z = \frac{ch(t)}{m} + \frac{\mu}{m}\dot{h}(t),$$

$$\ddot{z} + 2n\dot{z} + k^2 z = k^2 h(t) + 2n\dot{h}(t),$$

$$z = z_1 + z_2,$$

$$\ddot{z}_1 + 2n\dot{z}_1 + kz_1 = 0,$$

In accordance with the theory of differential equations [Kamke 1971] the general solution of this equation looks like

$$1.\left[\begin{array}{l} z_1(t) = e^{-nt}(C_1\cos(k_1 t) + C_2\sin(k_1 t)), \text{ if resis tan ce is low } n<k;\ k_1 = \sqrt{k^2-n^2} \\ \text{or } z_1(t) = ae^{-nt}\sin(k_1 t + \beta), \end{array}\right.$$

$$2.\left[\begin{array}{l} z_1(t) = C_1 e^{\lambda_1 t} + C_2 e^{\lambda_2 t}, \text{ where } \lambda_1 = -n + \sqrt{n^2-k^2};\ \lambda_2 = -n - \sqrt{n^2-k^2} \\ z_1(t) = e^{-nt}(C_1 e^{k_2 t} + C_2 e^{-k_2 t}) \text{ high resistance } (n>k)\ k_2 = \sqrt{n^2-k^2}, \end{array}\right.$$

3. $z_1(t) = e^{-nt}(C_1 + C_2 t) \quad n = k$- critical resistance.

Cases (2) (3) are damping not oscillating motions. Case (1) – damping oscillating motions.

Structure $z_2(t)$ – of partial solution of the differential equation depends on road shape, that is on $h(t)$.

Let

$$h(t) = h_0 \sin\left(\frac{Vt}{L}\right),$$

where:

$h(t)$ – the height of the road hill;
L – length of the road hill;
V – constant speed of the combine-harvester movement.

Let's designate

$$\frac{V}{L} = k_3,$$

$$h(t) = h_0 \sin(k_3 t).$$

Then

$$h(t) = h_0 \sin(k_3 t),$$

$$\dot{h}(t) = h_0 k_3 \cos(k_3 t),$$

$$k^2 h(t) + 2n\dot{h}(t) = k^2 h_0 \sin(k_3 t) + 2n h_0 k_3 \cos(k_3 t) =$$

$$= A_0 \sin(k_3 t) + B_0 \cos(k_3 t),$$

$$\ddot{z} + 2n\dot{z} + k^2 z = A_0 \sin(k_3 t) + B_0 \cos(k_3 t),$$

where:

$k^2 = \dfrac{C}{m}$, $n = \dfrac{\mu}{2m}$, $k_3 = \dfrac{V}{L}$,
$A_0 = k^2 h_0$, $B_0 = 2n k_3 h_0$.
$z_2(t) = A\sin(k_3 t) + B\cos(k_3 t)$, if $k_3 \neq k$,

that is,

$$\sqrt{\frac{C}{m}} \neq \frac{V}{L}.$$

If $\sqrt{\dfrac{C}{m}} = \dfrac{V}{L}$, then resonance will occur.

$$\dot{z}_2(t) = A k_3 \cos(k_3 t) + B k_3 \sin(k_3 t),$$

$$\ddot{z}_2(t) = -A k_3^2 \sin(k_3 t) + B k_3^2 \cos(k_3 t),$$

$$-Ak_3^2\sin(k_3t)-Bk_3^2\cos(k_3t)+2n(Ak_3\cos(k_3t)+Bk_3\sin(k_3t))+$$
$$+k^2(A\sin(k_3t)+B\cos(k_3t))\equiv A_0\sin(k_3t)+B_0\cos(k_3t),$$

$$\left.\begin{array}{l}\sin(k_3t)\left[-Ak_3^2-2nk_3+Ak^2-A_0\right]+\cos(k_3t)\times\\ \times\left[-Bk_3^2+2nk_3A+k^2B-B_0\right]\equiv 0,\end{array}\right| \Rightarrow$$

$$\left\{\begin{array}{l}A(k^2-k_3^2)-2nk_3B=A_0\\ B(k^2-k_3^2)+2nk_3A=B_0\end{array}\right| \Rightarrow \quad A=\frac{A_0+2nk_3B}{k^2-k_3^2},$$

$$B(k^2-k_3^2)+2nk_3\frac{A_0+2nk_3B}{k^2-k_3^2}=B_0,$$

$$B\left[k^2-k_3^2+\frac{4n^2k_3^2}{k^2-k_3^2}\right]=B_0-\frac{2nk_3A_0}{k^2-k_3^2},$$

$$B\frac{(k^2-k_3^2)^2+4n^2k_3^2}{k^2-k_3^2}=\frac{B_0(k^2-k_3^2)-2nk_3A_0}{k^2-k_3^2},$$

$$B=\frac{2nk_3h_0(k^2-k_3^2)-2nk_3k^2h_0}{(k^2-k_3^2)^2+4n^2k_3^2}=-\frac{2nk_3^3h_0}{(k^2-k_3^2)^2+4n^2k_3^2},$$

$$B=-\frac{2nk_3^3h_0}{(k^2-k_3^2)^2+4n^2k_3^2},$$

$$A=\left(A_0+2nk_3\frac{-2nk_3^3h_0}{(k^2-k_3^2)^2+4n^2k_3^2}\right)\Big/(k^2-k_3^2)=$$

$$=\left(A_0-\frac{4n^2k_3^4h_0}{(k^2-k_3^2)^2+4n^2k_3^2}\right)\Big/(k^2-k_3^2)=$$

$$=\left(k^2h_0-\frac{4n^2k_3^4h_0}{(k^2-k_3^2)^2+4n^2k_3^2}\right)\Big/(k^2-k_3^2)=$$

$$=\frac{(k^2-k_3^2)^2k^2h_0+4n^2k_3^2k^2h_0-4n^2k_3^4h_0}{\left[(k^2-k_3^2)^2+4n^2k_3^2\right](k^2-k_3^2)}=$$

$$= \frac{(k^2 - k_3^2)k^2 h_0 + 4n^2 k_3^2 h_0}{(k^2 - k_3^2)^2 + 4n^2 k_3^2} = \frac{h_0 (k^2 (k^2 - k_3^2) + 4n^2 k_3^2}{(k^2 - k_3^2)^2 + 4n^2 k_3^2}.$$

Thus

$$A = \frac{h_0 \left[k^2 (k^2 - k_3^2) + 4n^2 k_3^2 \right]}{(k^2 - k_3^2)^2 + 4n^2 k_3^2},$$

$$B = -\frac{2nk_3^3 h_0}{(k^2 - k_3^2)^2 + 4n^2 k_3^2},$$

$$z_2(t) = A \sin(k_3 t) + B \cos(k_3 t) \equiv H \sin(k_3 t + \beta_3),$$

where:

$H = \sqrt{A^2 + B^2}$,

$\mathrm{tg}\, \beta_3 = \frac{B}{A}$,

$Z(t) = Z_1(t) + H \sin(k_3 t + \beta_3)$,

At $t>T$, where T – is some time;

$Z(t) \approx H \sin(k_3 t \beta_3)$ – forced oscillation.

If $n<k$ – low resistance, then we have

$$Z(t) = ae^{-nt} \sin(k_1 t + \beta) + H \sin(k_3 t + \beta_3) \cdot$$

In Fig. 2 vertical oscillation of trailed assembly at the following meanings of the parameters is shown .

ℓ= 3 m; ℓ_1= 2,975 m; $\ell_2 = 0{,}025$ m; L = 1 m; V = 1,5 m/s;
M = 1800 kg; C = 250 000 N/m; μ = 1785 kg/s;
h_0 = 0,03 m; $Z_2(0)$ = 0; $\dot{Z}_2(0) = 0$.

The graph is built using the package of applied programs Maple 7.

```
VER : =proc (v, L, h0, M, l, l1, l2, c, MU, z0, zvo)
Local m, kk1, k1, k3, kk3, n, A0, B0, A, B, H, B3, AS, AKS, a, B1 ;
m : =M*l1/l ;  kk1 : =c/m ;  k1: =sqrt (kk1) ;  k3 : =v/L ;
kk3 : =k3*k3 ; n :=MU/(2*m) ;  A0 : =kk1*h0;   B0 : =2*n*k3*h0 ;
A : =h0*(kk1*(kk1- kk3)+4*n*n*kk3) / ( (kk1-kk3)**2+4*n*n*kk3) ;
B : =-2*n*k3*kk3*h0/((kk1 - kk3)**2+4*n*n*kk3) ;
H : =sqrt (A**2+B**2) ;  B3 : =arctan (B/A) ;
AS : =z0-H*sin (B3) ; AKS :=zv0+n*AS-H*k3*cos(B3) ;
A : =sqrt (AS**2+AKS**2) ; B1 : =arctan (AS/AKS) ;
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Plot (a*exp  (-n*t)*sin (k1*t+B1)+H*sin (k3*t+B3) , t=0 . . 3*Pi , thickness =3) ;
end:
VER (1.5 , 1.0 , 0.03 , 1800.0 , 3.0 , 2.975 , 0.025 , 250000 , 2000, 0 , 0);
```

The graph (Fig. 2) shows that during the initial period of time (0-9 sec) the influence of soil surface shape on cross oscillations of the assembly is marked and at (t>9sec) oscillations of the assembly are adjusted to the shape of the soil surface.

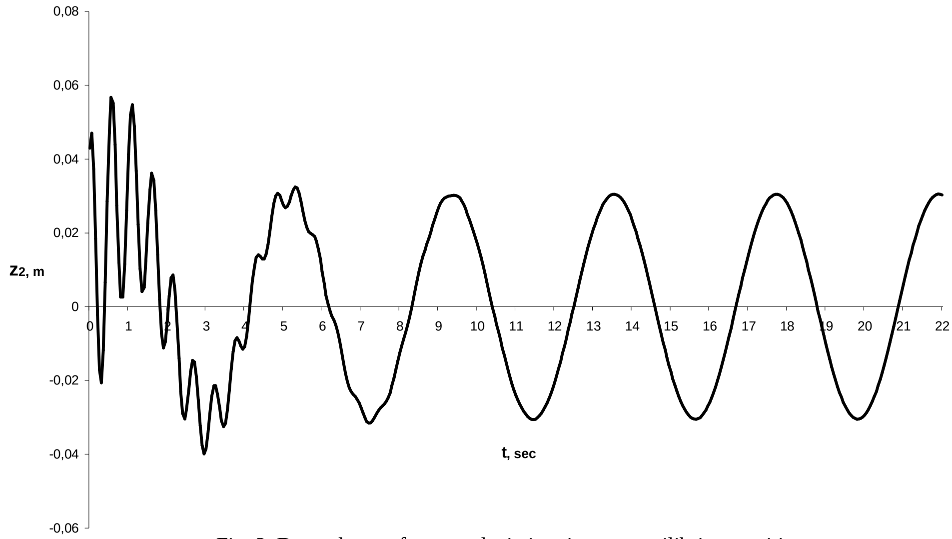

Fig. 2. Dependence of system deviation time on equilibrium position

REFERENCES

Horbovyi A.Yu. Construction of mathematical model of functioning of trailed flax harvesting assembly. Collection of scientific works of KMTI „Mechanisation of production processes of fishing husbandry, industrial and agrarian enterprises", Issue Kertch: KMTI P. p. 181–186.

Huskov V.V., Velev N.N., Atamanov Yu. E., Bocharev N.F., Ksenevych I.P., Solonskyi A.S. 1988: Tractors: Theory. Machine building. 376 p.

Kamke E. 1971: Book of reference on conventional differential equations. „Science", p. 576.