THE DRIVING THEORY OF THE COMBINE-HARVESTER FOR GATHERING FLAX

Volodymyr Bulgakov

National Agrarian University
Gueroyiv Obovny 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]

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

(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:

\[ m = \frac{Ml}{\ell} \]  

mass of the combine-harvester’s part performing rotary oscillation.

\[ Q_z = Q_z^{(p)} + Q_z^{(f)} + Q_z^{(e)}, \]

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

Fig. 1. Oscillation mechanical system with degree of freedom

\[ Q_z^{(f)} = -\frac{\partial F}{\partial \dot{z}} = -\mu(\dot{z} - \dot{h}), \]

\[ Q_z^{(e)} = 0, \]

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

\[ \frac{\partial T}{\partial \dot{z}} = m\ddot{z}, \]

\[ \frac{d}{dt}\left(\frac{\partial T}{\partial \dot{z}}\right) = m\dddot{z}, \]

\[ \frac{\partial T}{\partial z} = 0. \]

Substituting (2) in (1), we obtain

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

\[ \ddot{z} + \frac{\mu}{m} \dot{z} + \frac{c}{m} z = \frac{ch}{m} \frac{\dot{z}}{m}, \quad (3) \]

Let

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

Then

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

\[ z = z_1 + z_2, \]
\[ \ddot{z}_1 + 2n\dot{z}_1 + kz_1 = 0. \]

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

1. \[ z_1(t) = e^{-\nu t} (C_1 \cos(k_1 t) + C_2 \sin(k_1 t)), \] if resistance is low \( n < k; \ k_1 = \sqrt{k^2 - n^2} \)
   or \[ z_1(t) = ae^{-\nu t} \sin(k_1 t + \beta), \]

2. \[ z_2(t) = Ce^{\lambda_1 t} + C_2 e^{\lambda_2 t}, \text{ where } \lambda_1 = -n + \sqrt{n^2 - k^2}; \ \lambda_2 = -n - \sqrt{n^2 - k^2}; \]
   \[ z_2(t) = e^{-\nu t} (C_1 e^{k_1 t} + C_2 e^{-k_1 t}), \] high resistance \( n > k; \ k_1 = \sqrt{n^2 - k^2}, \)

3. \[ z_3(t) = e^{-n t} (C_1 + C_2 t) \quad n = k; \text{- critical resistance.} \]

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

Structure \( z_3(t) \) – of partial solution of the differential equation depends on road shape, that is on \( h(t). \)
Let
\[ h(t) = h_0 \sin \left( \frac{V_t}{L} \right), \]
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
\[ h(t) = h_0 \sin(k_3 t), \]
\[ \dot{h}(t) = h_0 k_3 \cos(k_3 t), \]
\[ k^2 h(t) + 2n\dot{h}(t) = k^2 h_0 \sin(k_3 t) + 2nh_0 k_3 \cos(k_3 t) = A_0 \sin(k_3 t) + B_0 \cos(k_3 t), \]
where:
\[ k^2 = \frac{C}{m}, \quad n = \frac{\mu}{2m}, \quad k_3 = \frac{V}{L}, \]
\[ A_0 = k^2 h_0, \quad B_0 = 2nk_3 h_0. \]

\[ z(t) = A \sin(k_3 t) + B \cos(k_3 t), \text{ if } k_3 \neq k, \]
that is,
\[ \sqrt{\frac{C}{m}} \neq \frac{V}{L}. \]

If \( \sqrt{\frac{C}{m}} = \frac{V}{L} \), then resonance will occur.
\[ \ddot{z}_s(t) = A k_3 \cos(k_3 t) + B k_3 \sin(k_3 t), \]
\[ \ddot{z}_s(t) = -A k_3^2 \sin(k_3 t) + B k_3^2 \cos(k_3 t). \]
\[-Ak^2 \sin(k,t) - Bk^2 \cos(k,t) + 2n(Ak_0 \cos(k,t) + Bk_0 \sin(k,t)) + \\
k^2 (A \sin(k,t) + B \cos(k,t)) \equiv A_0 \sin(k,t) + B_0 \cos(k,t).\]

\[
\sin(k,t) \left[ -Ak^2 - 2nk + Ak^2 - A_0 \right] + \cos(k,t) \times \left[ -Bk^2 + 2nkA + k^2B - B_0 \right] = 0,
\]

\[
\begin{aligned}
A(k^2 - k_i^2) - 2nk, B = A_0, \\
B(k^2 - k_i^2) + 2nk, A = B_0,
\end{aligned}
\]

\[
A = \frac{A_0 + 2nk \cdot B}{k^2 - k_i^2},
\]

\[
B(k^2 - k_i^2) + 2nk \cdot \frac{A_0 + 2nk \cdot B}{k^2 - k_i^2} = B_0,
\]

\[
B \left[ k^2 - k_i^2 + \frac{4nk^2}{k^2 - k_i^2} \right] = B_0 - \frac{2nk \cdot A_0}{k^2 - k_i^2},
\]

\[
B \left( k^2 - k_i^2 \right)^2 + \frac{4nk^2}{k^2 - k_i^2} = \left( k^2 - k_i^2 \right)^2 - \frac{2nk \cdot A_0}{k^2 - k_i^2},
\]

\[
B = -\frac{2nk \cdot h_0}{(k^2 - k_i^2)^2 + 4nk^2},
\]

\[
A = \left( A_0 + 2nk \cdot \frac{-2nk \cdot h_0}{(k^2 - k_i^2)^2 + 4nk^2} \right) / (k^2 - k_i^2) =
\]

\[
= \left( A_0 - \frac{4nk^4 \cdot h_0}{(k^2 - k_i^2)^2 + 4nk^2} \right) / (k^2 - k_i^2) =
\]

\[
= \left( k^2 \cdot h_0 - \frac{4nk^4 \cdot h_0}{(k^2 - k_i^2)^2 + 4nk^2} \right) / (k^2 - k_i^2) =
\]

\[
= \frac{(k^2 - k_i^2)^2 \cdot k^2 \cdot h_0 + 4nk^3 \cdot k^2 \cdot h_0 - 4nk^4 \cdot h_0}{(k^2 - k_i^2)^2 + 4nk^2} / (k^2 - k_i^2) =
\]
Thus

\[ A = \frac{h_0 \left[ k^2 (k^2 - k_1^2) + 4n^2k_3^2 \right]}{(k^2 - k_3^2)^2 + 4n^2k_3^2}, \]

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

\[ z_2(t) = A \sin(k_2 t) + B \cos(k_2 t) \equiv H \sin(k_2 t + \beta_3), \]

where:

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

\[ \tan \beta_3 = \frac{B}{A}. \]

\[ Z(t) = Z_0(t) + H \sin(k_2 t + \beta_3). \]

At \( t > T \), where \( T \) is some time;

\[ Z(t) = H \sin(k_2 t + \beta_3) \] \( \) – forced oscillation.

If \( n < k \) – low resistance, then we have

\[ Z(t) = ae^{-\alpha t} \sin(k_2 t + \beta) + H \sin(k_2 t + \beta_3). \]

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

\[ \ell = 3 \text{ m}; \quad \ell_1 = 2.975 \text{ m}; \quad \ell_2 = 0.025 \text{ m}; \quad L = 1 \text{ m}; \quad V = 1.5 \text{ m/s}; \]

\[ M = 1800 \text{ kg}; \quad C = 250 \text{ 000 N/m}; \quad \mu = 1785 \text{ kg/s}; \]

\[ h_0 = 0.03 \text{ m}; \quad Z_0(0) = 0; \quad \dot{Z}_0(0) = 0. \]

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

VER := proc (v, L, h0, M, l, l1, l2, c, MU, z0, zv0)
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 := k3^3; n := MU/(2*m); A0 := kk1*h0; B0 := 2*n*k3^3*h0;
A := h0*(kk1*(kk1-kk3)+4*n^2*k3^3) / ((kk1-kk3)**2+4*n^2*k3^3);
B := -2*n*k3^3*k3^3*h0/((kk1-kk3)**2+4*n^2*k3^3);
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(A**2+AKS**2); B1 := arctan(A/AS);
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

