Studies on the Pick Up Characteristics of the Spreading Chopped Straws (Part 11)

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Studies on the Pick Up Characteristics of the Spreading Chopped Straws (Part 11)

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The effect of many factors on the pick up characteristics of chopped straws was investigated and discussed with regard to both the fixed knives and the free-swinging flail knives. Both the rotating speed of knives and the inclination angle of the chute are the very influential factors in determining the pick up ratio. In addition to these factors, the chopped straws length, the clearance between knives and rotor housing, the distance between knives, the knife width are effective

carried out. In the first part of this study (Matsuo and Nguyen, 1978),

Obtaining a basic knowledge of the pick up characteristics of the chopped straws is the first step toward a better design procedure.

MATERIALS AND METHODS

I. Some definite factors and levels

Concerning this study, statistically significant factors were observed. Table 1 shows the summary of the factors and levels which were selected from the first part of this study.

Table 1. Allocation of some definite factors and levels.

Factors		Levels	
Rotating speed	N (rpm)	900	1100
Effective pick up radius	R (mm)	185.5	
Speed of carriage car	V (m/s)	0.4	
Knife width	B (mm)	30	
Distance of knives	C_K (mm)	15	
Refracting angle of knife	β (deg.)	46	
Length of chopped **straws**	L (mm)	50	80
Distribution density	ω (gr/cm^2)	9.6×10^{-2}	
Clearance between knives and rotor housing	C (mm)	50	

II. Measuring items and methods

1. ***Periodic vibration number and mass moment of the inertia of the flail knife***

The aluminum plate was fixed in the inside part of the bolt hole of the knife by an adhesive as shown in Fig. 1. The weight of this aluminum plate as compared with that of the knife may be neglected, and it is assumed that the friction between this plate and the supporting edge can be ignored in this case.

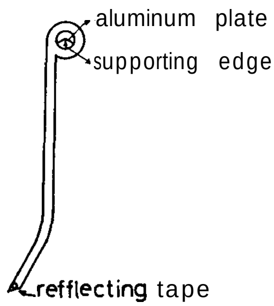

Fig. 1. Pick up knife used for measuring the periodic vibration number and the damping coefficient.

The periodic vibration number of knife was measured with the aid of the ultra-high-speed stroboscopic light source and camera. The camera shutter is left open during the entire motion, and as each flash occurs, the position of the reflecting tape which was pasted on the knife edge is recorded on the photographic film at that instant. The average periodic vibration number T of the knife is given by the following equation

$$T=60\,a/N_s \qquad (1)$$

where a=number of displacement of the reflecting tape.
N_s= flashing frequency of stroboscope (r-pm).

Since the flail knife is similar to the physical pendulum, the differential equation of motion may be given by

$$I\frac{d^2\theta}{dt^2} = -Mgb\ \sin\theta \tag{2}$$

where I = moment of inertia (kg•m•sec²).
θ = displacement of the knife from the vertical (rad).
t = time (sec).
b = distance from the pivot to the center of gravity (m).
M = mass of the flail knife (kg•sec²/m).
g = acceleration of gravity (m/sec²).

As the deviation angles are quite small, it may be assumed that sin $\theta \fallingdotseq \theta$.

Hence
$$\ddot{\theta}+\frac{Mgb}{I}\cdot\theta=0$$

The angular frequency is

$$\omega' = Mgb/I$$

$$\therefore\quad I = \frac{MgbT^2}{4\pi^2} \tag{3}$$

2. *Damping coefficient of the flail knife*

The aluminum plate shown in Fig. 1 was removed and the grease was inserted into the bolt hole. It is thought that the friction between the inside part of the bolt hole and the bolt is ignored and that there is only the damping working in this case. Therefore, the equation of motion may be written as

$$I\frac{d^2\theta}{dt^2} = -C\frac{d\theta}{dt}-Mgb\theta \tag{4}$$

where C= damping coefficient (kg•m•sec).

The solution of the differential equation (4) is given by

$$\theta = e^{-\frac{C}{2I}t}(A\cos\omega t + B\sin\omega t) \tag{5}$$

where A, B=constant

$$\omega = \left\{\frac{Mgb}{I} - \left(\frac{C}{2I}\right)^2\right\}^{\frac{1}{2}} \tag{6}$$

or
$$\theta = ae^{-\frac{C}{2I}t}\sin(\omega t+\varepsilon)$$

Since $\frac{d\theta}{dt}=0$ when θ is greatest,

then
$$\frac{d\theta}{dt}=ae^{-\frac{C}{2I}t}\left\{-\frac{C}{2I}\sin(\omega t+\varepsilon)+\omega\cos(\omega t+\varepsilon)\right\}$$

$$\therefore\quad a\sqrt{\left(\frac{C}{2I}\right)^2+\omega^2}\ e^{-\frac{C}{2I}t}\sin(\omega t+\varepsilon+\psi) = 0$$

where $$\tan\psi = -\frac{2I\omega}{C}$$

We may write that $t=t_n$ when θ is greatest, then

$$\omega t_n + \varepsilon + \psi = 2n\pi$$

$$\therefore \quad \frac{\theta_{n+1}}{\theta_n} = e^{-\frac{C}{2I}(t_{n+1}-t_n)} \cdot \frac{\sin[2\pi(n+1)-\psi]}{\sin(2\pi n-\psi)}$$

$$= e^{-\frac{\pi C}{I\omega}} \tag{7}$$

When the value of θ is approximately equal to zero, the following equation may hold

$$\frac{\theta_{n+1}}{\theta_n} = \frac{\gamma_{n+1}}{\gamma_n} \tag{8}$$

where γ_n is the amplitude of the physical pendulum.

When equations (6)~(8) are simplified, the damping coefficient of the flail knife is

$$C = 2\left|\ln\frac{\gamma_{n+1}}{\gamma_n}\right|\left\{\frac{mgbI}{4\pi^2+\left(\ln\frac{\gamma_{n+1}}{\gamma_n}\right)^2}\right\}^{\frac{1}{2}} \tag{9}$$

3. Deviation angle of the flail knife

The backward deviation angle of knife from radial position can be calculated by the following equation (Bosworth and Yoerger, 1966).

$$\lambda = e^{\frac{-Ct}{2I}}(A\cos kt + B\sin kt) - \frac{F(b+h)}{MbL\dot{\alpha}^2} \tag{10}$$

where $$k = \left[\frac{MbL\dot{\alpha}^2}{I} - \left(\frac{C}{2I}\right)^2\right]^{\frac{1}{2}}$$

F = instantaneous total force on the flail knife (kg).
h = distance from center of gravity of knife to knife edge (m).
L = radius of the rotor (m).
α = rotor position angle (rad).

4. *Outlet width of rotor housing*

The effect of the three different outlet widths of rotor housing on the

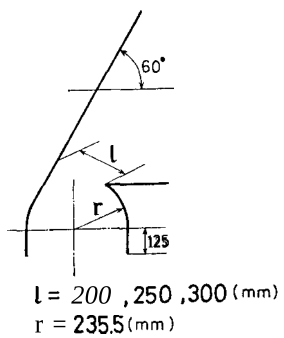

Fig. 2. Three different outlet widths of rotor housing.

pick up ratio was investigated.

5. Shape of ***under part of rotor housing***

Since the shape of under part of rotor housing has a considerable influence on the pick up characteristics, the experiments on this subject were carried out as to four types as shown in Fig. 3.

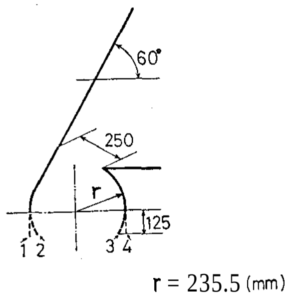

Fig. 3. Four types of the under part of rotor housing.

6. ***Inclination angle of the chute***

From a practical point of view, the bigger the inclination angle was, the higher the chute height became. However, the difference of inclination angle of the chute may be considered to have a large influence on the pick up ratio. As shown in Fig. 4, six steps of the inclination angle were tested.

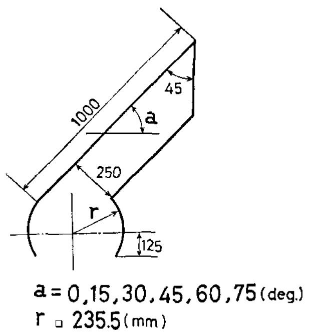

Fig. 4. Six inclination angles of the chute.

7. ***Trajectory of the discharging chopped straws***

It is assumed that the air resistance acting on the chopped straws discharged from the chute is proportional to the square of the velocity and that the friction between the straw material and the rotor housing can be ignored. Therefore, the theoretical equation of the trajectory may be written as follows:

$$M_s\ddot{x} = -kM_s\dot{x}^2 \qquad (11)$$

where k = constant

M_s = mass of chopped straw (kg)

or
$$\frac{d\dot{x}}{\dot{x}^2} = -k\mathrm{d}t$$

Since $\dot{x}=v_x$, $x=0$ when $t=0$,

$$\therefore \quad x = \frac{1}{k}\{\ln|kt+v_x^{-1}|+\ln v_x\} \tag{12}$$

$$M_s\ddot{y} = -M_s g - kM_s\dot{y}^2 \tag{13}$$

or
$$\frac{d\dot{y}}{g+k\dot{y}^2} = -\mathrm{d}t$$

$$\frac{1}{k}\int\frac{d\dot{y}}{(\sqrt{g/k})^2+\dot{y}^2} = -t+C$$

Since $\dot{y}=v_y$ and $y=0$ when $t=0$,

$$\dot{y} = \sqrt{g/k}\cdot\tan\{-\sqrt{kg}\cdot t+\tan^{-1}\sqrt{k/g}\cdot v_y\}$$

$$y = \frac{1}{k}\ln\frac{\cos(\sqrt{kg}\cdot t-\tan^{-1}\sqrt{k/g}\cdot v_y)}{\cos(\tan^{-1}\sqrt{k/g}\cdot v_y)} \tag{14}$$

At the highest point, the velocity $\dot{y}$ is zero. If t_1 is the time at which the straw reaches this point,

$$t_1 = \frac{\tan^{-1}(\sqrt{k/g}\cdot v_y)}{\sqrt{kg}} \tag{15}$$

The elevation of the point is

$$h = \frac{1}{2k}\ln\left(1+\frac{kv_y^2}{g}\right) \tag{16}$$

When an object falls freely after it reached the maximum height,

$$M_s\ddot{y} = -M_s g + kM_s\dot{y}^2 \tag{17}$$

or
$$\frac{d\dot{y}}{g-k\dot{y}^2} = -\mathrm{d}t$$

$$\frac{1}{2k}\sqrt{k/g}\ln\left|\frac{\dot{y}-\sqrt{k/g}}{\dot{y}+\sqrt{k/g}}\right| = t$$

$$\dot{y} = \sqrt{g/k}\tanh(\sqrt{kg}\cdot t)$$

Since $y=h$ when $t=0$

$$y = -\frac{1}{k}\ln[\cosh(\sqrt{kg}\cdot t)] + h \tag{18}$$

The initial velocity and the terminal velocity of the chopped straw were also measured with the aid of the stroboscope, and the average velocity is

$$v = \frac{d}{100}\Big/\frac{60}{N_s}$$

or $$v=\frac{dN_s}{6000}\text{(m/sec)} \quad (19)$$

where d = displacement of chopped straw (m)

Equations (11) through (19) may be used to the calculation of the theoretical trajectory of the movement of the discharging chopped straw.

8. *Effects of the rotor and the refracting angle of flail knife*

The rotating speed appeared to be an remarkable factor with respect to the pick up performance. At a low rotating speed, the wind force is not enough to blow off the chopped straws to the higher position and, on the contrary, at a high rotating speed, the spreading chopped straws seemed to be scattered widely. The most suitable rotating speed and the effect of the refracting angle of pick up knife were investigated in additional trials.

The direction of the inclination angle of the chute to the forward direction of the pick up machine and the shape of rotor housing as the logarithmic spiral were also tested for reference. These experimental apparatus are shown in Figs. 5-6.

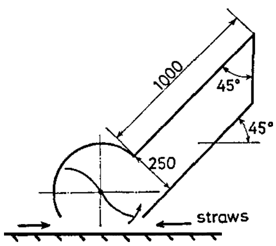

Fig. 5. Inclinating direction of the chute and the two *cases* of machine traveling direction.

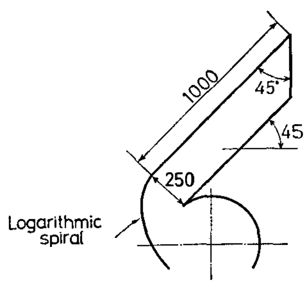

Fig. 6. Rotor housing with the shape of logarithmic spiral.

RESULTS AND DISCUSTION

The periodic vibration of knife was illustrated in Fig. 7 in the case of N_s = 3600 rpm. The periodic vibration numbers and the mass moment of the inertia of the flail knife were calculated from equations (1) and (3), and the results are shown in Table 2. Table 3 shows the results of the damping coef-

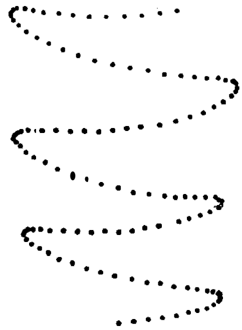

Fig. 7. Vibration of flail knife in the case of the flashing frequency of stroboscope of 3600 rpm.

Table 2. Data of periodic vibration number.

	N (rpm)		
	2400	3000	3600
a/cycle	27 28 27 28	35 34 35 34	42 41 42 41
Average	27.5	34.5	41.5
$T_i=\frac{60a}{N}$,	0.69	0.69	0.69
T_{mean}	(0.69+0.69+0.69)/3=0.69		
I	*1.76x10-4* (kg•m•sec²)		

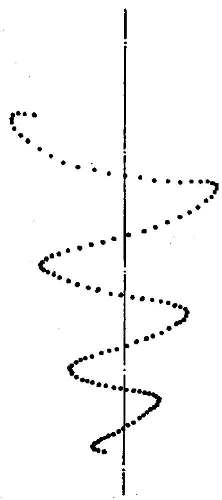

Fig. 8. Vibration of flail knife for the calculation of damping coefficient (N_s=3600 rpm)

Table 3. Data of damping coefficient of flail knife.

N(rpm)	$C\times10^{-5}$ (kg•m•sec)				Average
2400	22	25	22	29	24.5
3000	18	23	18	24	20.8
3600	21	26	16	22	21.3
	$C_{mean}\times10^{-5}=22.2$				

ficient of flail knife calculated from equation (9) and Fig. 8.

Since the resultant force of the chopped straws working on the flail knives was only about 0.40 kg. at 900 rpm and about 0.51 kg. at 1100 rpm, the deviation angle of knife was very small.

As shown in Table 4, in the case of the outlet width l is 250 mm, the pick up ratio obtained a good result in both cases of the chopped straws length. From the data shown in Table 5, it was found that the pick up ratio of the shape of under part of rotor housing with the closed type 2-3 increased considerably.

Table 4. Influence of the outlet width of rotor housing on the pick up ratio.

Chopped straw length L(mm)	Outlet width l (mm)		
	200	250	300
50	0.61	0.63	0.58
80	0.65	0.63	0.61

Table 5. Effect of the shape of under part of rotor housing on the pick up ratio.

N (rpm)	L (mm)	Type			
		1-4	2-4	2-3	1-3
900	50	0.64	0.68	0.71	0.65
	80	0.67	0.68	0.69	0.67
1100	50	0.63	0.65	0.70	0.61
	80	0.66	0.68	0.73	0.63

Table 6 shows that the smaller the inclination angle of the chute and the higher the rotating speed, the more the pick up ratio increases, however, at the bigger inclination angle of the chute, the pick up ratio was inclined to decrease. One of the major reasons for the low pick up ratio appears due to the result of the blockade of the chopped straws which gave a large influence upon the air blast grew by the revolution of the pick up knives. It is necessary to install the chute with a large inclination angle, in general, in order to load conveniently the discharging chopped straws into wagon with a large capacity. The data shown in Table 6 suggest that the inclination angle of the chute at about 45 deg. is suitable for the practical pick up machine.

Table 6. Effect of the inclination angle of the chute on the pick up ratio.

N (rpm)	*L* (mm)	Inclination angle of chute (deg.) 0	15	30	45	60	75
900	50	0.90	0.79	0.66	0.60	0. 52	0.47
	80	0.90	0.80	0.67	0.62	0. 63	0. 52
1100	50	0.92	0.92	0.82	0.73	0. 62	0.64
	80	0.93	0. 90	0. a2	0.75	0.72	0.70

The theoretical trajectory of chopped straws which was determined by the computer compared closely with the values obtained from the photographic films as shown in Figs. 9 and 10.

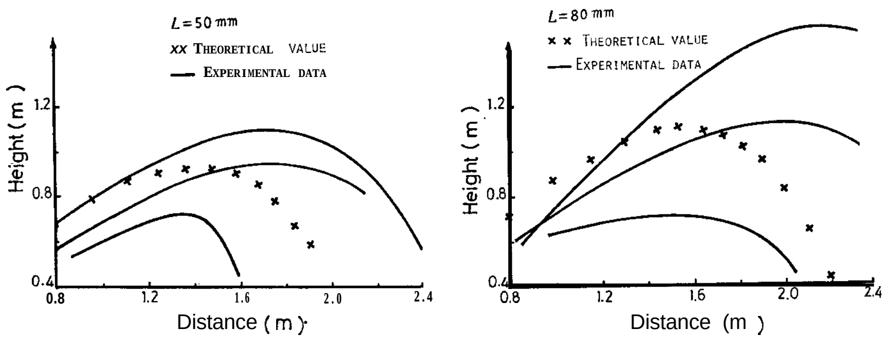

Fig.. 9 Trajectory of chopped straws (N=900 rpm).

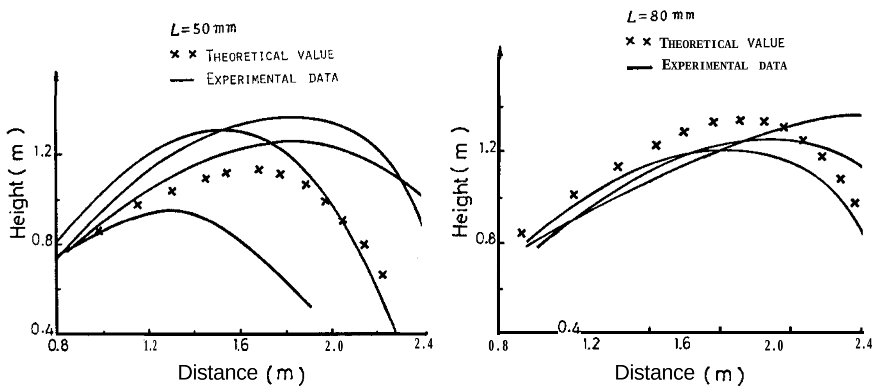

Fig. 10. Trajectory of chopped straws (N=1100 rpm).

The refracting angle of the pick up knife does not have a pronounced effect on the pick up ratio, and there is no significant difference between the fixed knives and the flail knives on the pick up ratio as shown in Table 7. Fig. 11 shows that the most suitable rotating speed is about 900~1300 rpm for the chopped straws pick up.

Table 7. Effect of three different types of the refracting angle on the pick up ratio.

N (rpm)	L (mm)	β (deg.) 32	46	60
900	50	0.60*	0.62*	0.61*
	80	0.62	0.61	0.61
1100	50	0.71*	0.69*	0.68*
	80	0.68	0.64	0.68

* with the fixed knives

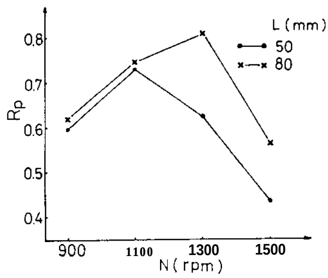

Fig. 11. Effect of rotating speed on the pick up ratio.

Unfavourable pick up ratio was found in neither the logarithmic spiral shape nor the case shown in Fig. 5 as mentioned above.

CONCLUSION

A result of this investigation is summerized as follows:

1. There is scarcely difference of the pick up ratio between the fixed knives and the flail knives.
2. The suitable shape of the under part of rotor housing is the closed type 2-3 as shown in Fig. 3.
3. The pick up ratio is considerably favourable when the rotating speed is about 900-1300 rpm.
4. The forward speed of the machine has little effect upon the pick up ratio.
5. The most suitable inclination angle of the chute is 0 deg. at the low rotating speed, however, the practically favourable angle is about 45 dg..
6. The logarithmic spiral shaped outlet of rotor housing and the case showed in Fig. 5 were not suitable for pick up machine.

The authors suggest that the performance of the pick up machine with the aid of a blower also shows a good result in the case of the inclination angle 0 deg. of the chute at a low rotating speed.

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